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California Institute of Technology

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STUDY OF THE SANTA ANA WINDS OF THE LOS ANGELES BASIN

Hubert E. Strange

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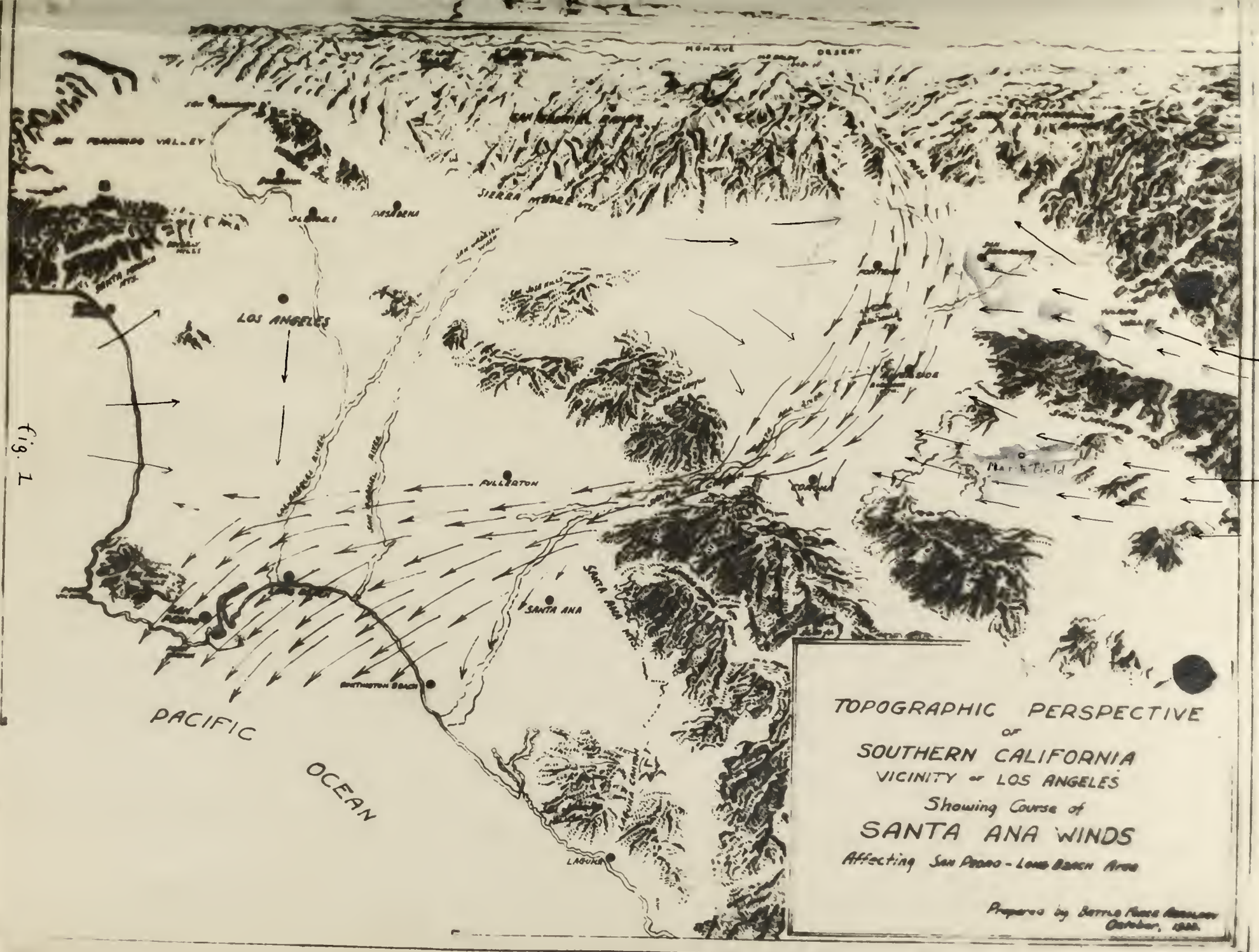
MOHAVE DESERT
SAN FERNANDO VALLEY
SIERRA MADRE MTS.
PASADENA
LOS ANGELES
SAN GABRIEL MTS.
SAN BERNARDINO
Norton Field
FULLERTON
SANTA ANA
SANTA ANA MTS.
HUNTINGTON BEACH
PACIFIC
OCEAN
LAGUNA
TOPOGRAPHIC PERSPECTIVE
OF
SOUTHERN CALIFORNIA
VICINITY OF LOS ANGELES
Showing Course of
SANTA ANA WINDS
Affecting San Pedro - Long Beach Area
Prepared by Battelle Flood Research
October, 1938

fig. 1

STUDY OF THE SANTA ANA WINDS OF THE LOS ANGELES BASIN

Thesis by

Hubert E. Strange

In Partial Fulfillment of the Requirements

for the Degree of Master of Science in Meteorology

California Institute of Technology

1953

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Lt. (jg) Hubert B. Strange, U.S.N.

April 1938

California Institute of Technology

STUDY OF THE SANTA ANA WINDS OF THE LOS ANGELES BASIN

Introduction

This study of Santa Ana winds is made with the object in view of enabling forecasters to tell when high velocity SE winds will affect San Pedro Harbor. Navy aerologists have been able to give warning of the development of this condition in all cases, but have found that in many cases when this condition was forecast high winds often appear aloft but do not reach the surface.

Some conclusions have been reached during this study which it is hoped will prove an aid to forecasting.

With the closer network of stations now available, and with more frequent balloon soundings and aerograph records, it is thought that definite criteria will soon be found which may enable the forecaster to be more certain in giving out Santa Ana warnings.

The Santa Ana winds of Southern California, sometimes called Desert Winds or Foehn Winds, may be of such great force that they are capable of doing great damage in the area which they affect.

The origin of the name of the winds is controversial. It was probably named by the early Spaniards either because of its occurrence upon some early Santa Ana's day or because of its frequent manifestation in the vicinity of Santa Ana Canyon or Town. An ingenious explanation of the name is that it originated from the Mexican letters in whose language "Santana" means "Big Wind" or "Devil Wind."

It is necessary to define what winds will be considered as Santa Ana winds in this paper. In this writer's opinion, it is necessary

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*Lt. Comdr. William A. Mason, U.S.N.

Introduction

that the wind be caused by an area of high pressure over the Great Basin of North America, and that the wind occur in the area to the southwestward of the San Gabriel and San Bernardino Ranges of the Coastal Mountains. This area is called the Los Angeles Basin and the San Fernando Basin. Another limitation to be included in the definition of Santa Anas is that an ENE wind of about 20 knots blow at the surface in the San Pedro Harbor.

High Santa Anas are those which give high ENEasterly winds aloft at San Pedro due to the gradient from the Great Basin, but are only marked at the surface by low humidity, high temperature and clear to hazy skies.

The Santa Ana winds manifest themselves most often as a stream of dry air flowing through Cajon Pass and continuing from there on to the sea in the vicinity of San Pedro, during which travel a great deal of dust is picked up.

Cajon Pass is about 17 miles long and quite steep on each side. It extends generally north and south, turning to the southeast at its rather narrow mouth. At the top of the pass on the edge of the Mojave Desert at Daly Mine, the elevation is 3700 ft.; at the bottom of the pass at Fontana the elevation is 1700 ft. The accompanying photograph shows the probable path of the air currents at the surface during a Santa Ana.

Observations from an aeroplane flying in this vicinity show that another stream of air from San Gorgonio Pass to the south also takes part in this flow.

Observers have described a Santa Ana as a stream of air, defined by the dust picked up in the turbulent flow, which may be of

moderate height and with a well defined width of about five miles. This can well be believed when it is considered that the Santa Ana of 11-12 January 1923, which did damage exceeding $1,000,000 in Los Angeles and Orange Counties blowing down oil derricks, unroofing houses, and blowing citrus trees down, gave winds of less than 12 miles per hour in Los Angeles and caused little if any effect in San Diego. During this storm a maximum velocity of 84 m.p.h. was observed in Riverside and 54 m.p.h. on the U.S.S. Augusta anchored at San Pedro.

During a period when a well developed HIGH over the Great Basin is causing Santa Ana winds, Foehn winds of high velocity occur all along the mountain ranges and are particularly severe near places where the mountain walls are broken by canyons. The writer observed this during the Santa Anas of October 1935. Then in some parts of Altadena near Eaton Canyon high Foehn winds were experienced, in other nearby parts no effects were felt.

At Glendale in the San Fernando Valley, considerable damage has been done by winds of the same type which come through canyons near there. On November 22, 1930, at the Grand Central Airport in Glendale, a tri-motored plane was torn from its anchorage during the early morning

hours and was rolled by the wind a half mile across the field, where it was turned upside down and wrecked. Considerable other damage was done by this same wind. At other places the wind generally blows from practically the same direction during the storm, but at Glendale it would blow from NE 50 m.p.h. and then suddenly shift to SSW and blow nearly as hard as before.

This storm gave winds aloft up to 8000 ft. of over 110 m.p.h. preventing a plane which had taken off for San Francisco from making any headway.

High winds from the continent are also experienced near Santa Barbara, San Francisco and in the Tia Juana Valley near San Diego. These will not be considered in this study although they result from similar synoptic conditions and might well be classed as Santa Anas.

Very often the only effect of a high pressure area in the Great Basin is to cause a rise of temperature and low humidities along the sea coast as the normal stagnant maritime air is displaced by Foehn air from the interior. In the summer it is the only effect. At Fontana, an air field near the mouth of Cajon Pass, northerly winds of at least force 5 are generally experienced when there is a HIGH in the Great Basin. This may increase to force 8 without any Santa Ana winds being experienced in San Pedro Harbor.

Another interesting feature of these winds is described in a paper by Lt. Comdr. William A. Mason, U.S.N., who states "Another phenomenon accompanying the Santa Ana is the electro-static effect. During the progress of the desert wind frictional electrical charges due to the extreme dryness of the air are noticed on nearly every object

that is insulated from the ground.

"Moving automobiles often gather a heavy charge of static electricity on the body varnish, which, when one on the ground reaches for the door in entering, passes into the hand with an audible snap and with consequent shock."

A garage mechanic who lives in the vicinity of Santa Ana has told the writer that during the Santa Ana of October 22, 1935, cars were stalled because of the failure of ignition systems caused by the static electricity.

Literature

In order to understand the Santa Ana or Foehn winds of Southern California by reading of them, it must be realized that each writer who describes them has different motivations for his interest. The present study was made primarily with an interest in San Pedro Harbor.

In 1933 Lt. Comdr. T. A. Mason, U.S.N., in his "The Santa Ana or Desert Storm of Southern California" gave a very good description of the Santa Ana and its effects from the viewpoint of the seaman.

In the Lehrbuch der Meteorologie, Hann-Süring, there is a chapter on "Besondere Arten der Zyklonalen und antizyklonalen Winde in Gebirgsländern." This deals chiefly with Foehn winds in the Alps, and quotes many European authors who have studied these phenomena.

In a paper "Foehn Winds of Southern California" by Irving P. Krick, the Foehn effect is clearly shown in Cajon Pass by considering Baldy Mesa at the top of the pass and Fontana at the bottom.

In an article "Desert Winds in Southern California" in the Monthly Weather Review of October 1931, Mr. Floyd D. Young has studied the Santa Ana winds chiefly in relation to the citrus industry which is affected by these winds.

A detailed description of "Santa Anas" is also contained in a paper "The Santa Ana" compiled and distributed by Commander Aircraft, Battle Force in 1931.

Included in the paper by Lt. Comdr. T. A. Mason, and that by Chief Aerographers C. S. Alston and L. F. Brown, U.S.N., the following dates of Santa Ana winds at San Pedro Harbor are listed:

Date	Time Began	Duration Hours	Highest average hourly velocity Knots	Max. Gusts Knots	Relative Humidity
28 Dec. 1924	?	?	?	?	?
30 Dec. 1929	0700	11	[illegible]-31	?	14%
28 Dec. 1929	1100	12	[illegible]-22	?	30%
21 Nov. 1930	2000	24	[illegible]-35	48	29%
20 Dec. 1930	1030	24	[illegible]-23	?	30%
23 Nov. 1931	1900	9	[illegible]-33	45	24%
24 Nov. 1931	1600	6	[illegible]-31	45	25%
23 Jan. 1932	0800	11	[illegible]-26	37	37%
24 Oct. 1932	1400	11	[illegible]-31	46	10%
10 Jan. 1933	0000	18	[illegible]-34	63	21%

In papers entitled "Notes Concerning Santa Anas" from Commander Cruisers, Scouting Force, the following is found:

1. Santa Anas can be expected to occur during the late fall and early winter months. Reason: Cold air outbreaks move from N and NW giving necessary high pressure areas.

2. They can take place at any time of day or night, but conditions are more favorable for occurrence in early morning hours. Reason: The necessary pressure gradient can be built up day or night; however, at night the radiation cooling assists in this building up, whereas the sun's radiation during the day tends to retard this increase of pressure.

3. When a high pressure area is situated to the northward, a low pressure area at or to the southward of extreme Southern California, and the pressure difference between Nevada and San Pedro is over 45 hundredths of an inch, a Santa Ana of considerable force can be expected somewhere off the Southern California Coast. If this pressure difference is between 35 and 45 hundredths of an inch, a mild Santa Ana can be expected.

4. The force of the winds is also dependent on the trend of the isobars. The greater the northeasterly and easterly wind components acting, the greater will be the flow down the Cajon and San Gorgonio Passes. Also northeasterly and easterly wind components give a greater possibility of the storm occurring in the Long Beach-San Pedro area.

5. Generally clear skies and good to excellent visibility precede a storm of this type, yet there will be cases when this is not true, as was the case preceding the storm of 11 January 1933 in San Pedro Bay. Reason: The hot, dry air flowing from inland dissipates cloud formations and clears the atmosphere of haze, due to moisture suspensions.

6. Preceding a Santa Ana, the difference between the wet and dry bulb thermometer readings usually varies from 10 degrees to 25 degrees Farenheit. Again reference is made to the storm of 11 January 1933 where this difference did not occur until the storm had actually arrived. It is not well to place too great a confidence in these readings, as an indication of approaching Santa Anas. In this connection the following data are noted: Between March 1933 and August 1935, while the Scouting Force Aerological Unit was in San Pedro Bay, there were 82 days when the difference between the wet and dry bulb thermometer was 10° F. or greater, and in some cases as much as 24° F. On only one of these days did a

Santa Ana occur at San Pedro anchorage, and on only two other of these days was dust observed in the air, yet mild Santa Anas may have occurred elsewhere along the coast.

Notes 7, 8 and 9 not included here.

Description of Santa Ana of January 21, 1936, as seen from air by

Lt. O. P. Zimmerman, U.S.A.

On January 21, 1936 at 0900, Lt. O. P. Zimmerman, U.S.A., took off from March Field, California, into a light west wind and observed a Santa Ana for four hours. The accompanying sketch, Fig. 1, shows the air currents as observed.

There was a high (30.30) centered at the northern border of Nevada and giving a pressure gradient to Los Angeles of .35/100 in hg. from Winnemucca with a temperature difference on the morning of the 21st of 26° F. The isobars ran N. from Los Angeles and the upper winds were divergent light northerly at levels below 8000 ft. and force 5 from NW. at Los Angeles.

A stream of air was flowing down Cajon Pass which began to raise dust in the agricultural district around Pomona. This stream was well defined even before it raised dust at Pomona, because the action of the wind on the orange groves and wind breaks between Pomona and the foot of the pass could be seen. By flying through the air stream at various levels the trough plane of the stream could be observed.

After dust became mixed with the air it could be observed to hit the earth's side of Santa Ana Canyon and pass out to sea so that its southern edge was at Newport Beach and northern edge at Huntington Beach.

A current of air was flowing out of San Gorgonio Pass and moving through Yucaipa Valley and over the San Jacinto Mountain passes to join the air stream from Cajon Pass. Another stream of air was diverging at Corona some moving north and joining the main stream while some moved south to the Santa Ana Mountains.

At the sharply defined surface boundary of the main stream of air, the air from the vicinity of Corona which was moving in the opposite direction of the main stream could be observed being sucked into the main stream causing whirls of dust at the border of the main stream.

Air from the San Fernando Valley was moving over Los Angeles southward to join the main stream on a line from Fullerton; however, along this line due to the diminished velocity of the air from the Santa Ana Canyon, no well defined line of discontinuity between these streams could be observed.

The hazy stream of air extended out to Catalina Island at the time of take off (0900 January 21 so the flow from El Cajon must have started before this time.

The air from San Fernando Valley was very stable, as a smoke pall from Los Angeles strung out to southward during all of the observation.

Later in the day a sea breeze was observed to move in from Santa Monica Bay. At about this time the stream of air from Cajon Pass shifted so that it impinged on the north side of Santa Ana Canyon and then shifted from between Newport Beach and Huntington Beach to between Long Beach and Huntington Beach.

Very marked turbulence existed at the boundary of the main stream of air, but in the stream itself there was less turbulence than at the boundary. The action of the air in carrying dust aloft to 6000 ft. shows,

however, that the turbulence within the stream must have been considerable, and also shows that 6000 ft. is about the upper limit of the turbulent flow.

On landing at March Field at 1350 a strong east wind was blowing.

These observations help explain the apparent sharp deflection of the winds from Cajon Pass to Santa Ana Canyon, as the strong current from San Gorgonio Pass, aided by the San Jacinto Mountains, would produce a deflection eastward to explain the flow.

Santa Ana of January 11, 1933

From 5 January 1933 until after 14 January, the pressure in the Great Basin remained High above 3026 at Winnemucca. The temperature ranged between 8° and 66°F. At Los Angeles the pressure varied between 3016 and 2998 from January 4 to January 10 [illegible], falling to 2994 January 10 P.M., then rising to 3024 January 11 P.M. During this period the Aleutian LOW was well developed and the Pacific anticyclone prominent. January 8 P.M. the Aleutian LOW was displaced southward centered at L 53 Λ 137 by January 9.A.M. an intense LOW had moved into Canada and a front passed the NW states bringing fresh Polar Pacific air behind it. The Pacific HIGH built up northward until January 10 A.M. it was centered at L 43 Λ 123, 30.50 . The isobars then showed a tongue of high pressure extending into the Great Basin. The pressure then built up until on the morning of January 11 it was 3070 at Winnemucca, giving a pressure gradient between Winnemucca and Los Angeles of 50/100 in.bg. mi.

On January 10 A.M. there was a rapidly moving cold front with Pp air behind it just past Pt. Arguello running east to about Santa Fe, N.M., thence NE into a LOW 29.10 just west of Lake Superior. By January 10 P.M. the front was in the vicinity of San Diego and a LOW 2986 was in the vicinity of Phoenix. The temperatures in the Great Basin were + 6 to + 8 with + 2 behind the front and √+ 4 along it.

During the night after this map, the Santa Ana occurred which caused great damage in San Pedro and vicinity; by the morning of January 11 the H.P. had moved far south and Santa Ana winds were prevalent at San Pedro.

These winds were above normal for the gradient during their maximum hourly velocity, but the H.P. and LOW helped induce them (see Fig. 10).

At Long Beach a light south wind was reported until midnight January 10, when the wind shifted to east and increased rapidly in velocity until it reached a velocity of 50 knots between 0400 and 0500 from ESE. The winds then decreased steadily to 19 knots at 1000, then increased to 33 knots between 1100 and 1200, gradually diminishing during afternoon. After 1600 the wind became light and variable. This Santa Ana did damage in the harbor and around San Pedro and Long Beach of one million dollars.

The following detailed description of the conditions existing from October 19 to October 23, 1935, with maps analyzed by Dr. Sverre Petterssen at the California Institute of Technology, is included. It would be desirable to include detailed information for other cases, but circumstances do not permit at this time; however, it is hoped that they can be added at some later date.

Any one interested in making a further study of this subject may obtain additional data now available by writing the author.

Series 17 to 23 October 1935

On the morning of October 19, 1935, a LOW was in Wyoming and the Pacific HIGH was centered at L 35 N / 150 W. The upper winds in the rear of the LOW showed an influx of PP air of sea-level, Lat. 40, T. 62°. By evening the LOW had moved east to North Dakota and with a pressure of about 30.30 over the Great Basin, the isobars were north and south. The upper winds still show PP air entering the continent from a generally NW direction. The upper winds at Los Angeles were NW, force 5 at high levels. Tendencies were + 3 over the Great Basin.

On the morning of October 16, an irregular round HIGH 30.33 was centered at the northern border of California. The gradient was $\frac{.07 \text{ in.hg.}}{100 \text{ mi.}}$ and the isobars ran NW from Los Angeles. A small HIGH was centered at L 35 ʎ 132 W and at L 47 ʎ 175 E a HIGH 30.40.

Just after this map at 0700 PST, wind at Fontana, which had been light and variable, became 18 m.p.h. gusty from NNW with T 55°, and dew point 34.

The wind became north and increased until 10000 when it was 37 m.p.h. gusty with T 66° , dew point 33. At 1700 the time of the P.M. map, the wind was N 25 m.p.h., T 73° , D.P. 26, at Los Angeles T 65°, D.P. 31, with light west wind. At San Pedro

0700	T 62°	R.H. 66	D.P. 66	E 8 knots	clear	30.05
1200	T 62°	R.H. 61	D.P. 52	NW 16 "	"	30.03

maximum wind W 20 knots at 1400 to 1500, going to NW 9, 1700, NE 8, 1900 to 2000.

On the P.M. map there was a HIGH at the northern border of Nevada 3043 with a gradient $\frac{.10 \text{ in.hg.}}{100 \text{ mi.}}$ and the isobars running NNW from Los Angeles. From the center of the HIGH to Los Angeles the gradient was $\frac{.08 \text{ in.hg.}}{100 \text{ mi.}}$. The upper winds were divergent from the HIGH and from NW at Los Angeles. The Pacific HIGH had moved SE.

The temperatures and dew points were: at Daggett 63-26, Reno 54-27, Winnemucca 50, and Los Angeles 65-31.

At Burbank 1700 the wind was from NE 12 m.p.h., T. 69°, D.P. 40. This increased and at 2300 was NE 16, T. 56°, D.P. 40.

Wind at San Pedro, W 15 knots, clear

1600	T. 62°	R.H. 44	D.P. 47	W 15 knots	29.98
2000	T. 63°	R.H. 61	D.P. 52	NW 6 knots	30.04

At 1300 the winds shifted from NW 6 to N 5 and at 2000 became NW until at 2200 the hourly average was 21 knots from NW. The wind stayed NW 6 until 0300, then was northerly.

At 2000 the temperature and dew point were 66 and 52 with a relative humidity of 61; by 0800 the next morning temperature and dew point were 69-34 with a relative humidity of 28 and an NNE wind 5 knots.

During this night winds from the mountains of considerable intensity were experienced in Altadena.

On the A.M. map October 17, there was a HIGH centered over the Great Basin of 3056 with the isobars from Los Angeles running W and a gradient of $\frac{.10 \text{ in.hg.}}{100 \text{ mi.}}$ with generally rising tendencies + 4 in the center. There was also a HIGH of 3040 at L 35 Λ 130 and L 45 Λ 175W. The upper winds were force 4 to 6 from the Great Basin NNE.

At Fontana the wind was N 36 gusty T 64°, D.P. 23. This wind increased until 0300 PST when it was N 43 m.p.h. The temperatures and dew points were: Daggett 51-21, Reno 23-20, and Winnemucca 24. Los Angeles had NW force 3 with T 70° and D.P. 29, showing it was in Foehn heated air.

At Burbank the wind had decreased to 3 m.p.h. from NNE, T 70°, D.P. 28, showed Foehn winds. At San Pedro

0300	T 61°	R.H. 28	D.P. 34	NNE 5 knots	30.14
1200	T 63°	R.H. 3	D.P. 15	N 6 knots	30.10

Wind San Pedro averaged NE 3 during 0000 to 0700.

On the 17 P.M. map the Great Basin HIGH was still centered at the NW corner of Nevada with 30.60 pressure. The North Pacific HIGH had elongated to the east and was about 30.30. The isobars from Los Angeles

were still NW but a trough had begun to form over the Arizona-New Mexico border. The upper winds still were from NW from the Great Basin, and all the Southern California coast was under the influence of Foehn air. The gradient was now $\frac{.12}{100}$ in.hg. but the tendencies were falling on the wedge toward Los Angeles above -3 and in the center were about 0.

Temperatures were: Winnemucca 56, Longett 70-24, Reno 60-23, Los Angeles 80-24. The wind at Los Angeles was NNW force 4 and the upper wind NNW force 6.

At Fontana the wind was NW 34 gusty 75-22. After this map the wind reduced until at 2200 it was NNW 9 after which it again increased at Burbank. At 1700 the wind had become 24 m.p.h. from NW with T 80°, D.P. 24 from which it reduced until at 2200 it was south 2 m.p.h.

At San Pedro

1600	T 63°	R.H. 32	D.P. 41	NNW 17 knots	30.06
2000	T 63°	R.H. 30	D.P. 36	E 12 knots	30.09

From 1200 to 1900 the wind averaged NNW 16 knots, but 2200 to 2400 it was again NW 8 knots.

On the A.M. map October 18, the Great Basin HIGH had spread to the East but was centered over Utah 30.56 with falling tendencies. The upper winds showed divergence over California and the gradient was now $\frac{.10}{100}$ in.hg. with the isobars from Los Angeles running to the NNE. The north Pacific HIGH was still spreading eastward with about 30.60 at its center.

Temperatures were: Winnemucca 56, Longett 43-27, Reno 23-20, and Los Angeles 71-25, showing Foehn air at Los Angeles. Fontana had wind from NNW 27 m.p.h. gusty and 66-1°. This wind had increased from 9 m.p.h. at 2240 and reached 33 m.p.h. at 1000.

At San Pedro

0800	T 62°	R.H. 22	D.P. 32	calm	clear 30.02
1200	T 62°	R.H. 27	D.P. 39	W 13 knots	29.93

On the U.S. map the U.S. HIGH now was only 30.30 with falling tendencies -5 at the center and toward Los Angeles falling -4. A definite trough had now formed over the Gulf of California 29.86 at Yuma. The upper winds showed NW to W force 4 near Los Angeles. The north Pacific HIGH was still approaching and was about 30.60 at L 47 A 135.

At Fontana the wind was W 24 m.p.h., T 80°, D.P. 30; after 2000 the wind died down to 15 m.p.h., the dew point gradually increased and the temperature decreased so that this continued Santa Ana wind at Fontana may be considered to have ended. Los Angeles had a T 80° and D.P. 32 with NNW wind force 4 at 1500, showing Foehn air.

The gradient was now $\frac{.08}{100}$ in.hg. mi. T at Winnemucca 64°, Daggett T 73°, D.P. 35, Reno T 65°, D.P. 10.

At San Pedro

1600	T 63°	R.H. 30	D.P. 42	W 16 knots	29.87
2000	T 62°	R.H. 68	D.P. 54	W 16 knots	29.90

At Fontana the wind was W 24 m.p.h., T 80°, D.P. 30, but after 2000 the wind decreased to W 15 m.p.h., and the dew point and temperature gradually decreased so that the continued Foehn winds may be considered to have ended.

At San Pedro

1600	T 36°	R.H. 30	D.P. 42	W 16 knots	29.87
2000	T 62	R.H. 54	D.P. 54	W 16 knots	29.90

On the evening of the 19th a lo[illegible] 29.60 which had been moving from NW to SE was over Wyoming, and fresh Pp air was now entering over the NW states, causing a decided decrease in surface temperatures. The Pacific

HIGH was centered at L 47 ∧ 147, 30.60. Pressures had now begun to rise over the NW states. Two wedges were beginning to appear on the HIGH, one entering over Washington and Oregon, the other extending south at ∧ 135 W.

On the morning of October 20 the HIGH appeared similar to the former evening, at this time the upper winds over the NW coast at high levels were force 8 from the West, and a HIGH was beginning to form in the Great Basin.

On the evening of the Pacific HIGH had rotated almost N and S and a LOW was forming over Utah. The upper winds over the NW states were now moderate westerly while at Redding, Calif., they were W force 10 at 14000 meters.

At San Pedro, October 20

0800	T 55°	D.P. 55	R.H. 79	N 12 knots	29.97
1200	T 54°	D.P. 54	R.H. 66	SW 8 knots	29.92
1600	T 57°	D.P. 57	R.H. 84	WSW 20 knots	29.89
2000	T 55°	D.P. 53	R.H. 94	W 8 knots	29.93

On the morning of October 21 the Pacific HIGH was centered at L 45 N ∧ 135 W, axis N and S, and again a wedge extended into the coast at the northern border of California, and a HIGH appeared to be forming in the Great Basin. The LOW was now over Western Colorado 29.70. Upper winds were W force 6 to 8 along the coast.

On the evening of October 21 the LOW had moved to New Mexico and the Pacific HIGH was centered at L 45 N 133 W., 30.50, its main axis N and S with a wedge extending into the Great Basin.

At San Pedro October 21

0800	T 60°	D.P. 53	R.H. 73	NE 4 knots	30.00
1200	T 65°	D.P. 55	R.H. 74	W 7 knots	29.97
1600	T 63°	D.P. 53	R.H. 74	WSW 15 knots	29.93
2000	T 60°	D.P. 57	R.H. 89	NW 5 knots	29.93

On the morning of October 22 the Pacific HIGH had the same general shape and now there was only a trough remaining of the LOW which had been in New Mexico. There was a HIGH 30.60 over Vancouver and another 30.50 at L 43 ⅄ 130. The isobars from Los Angeles were now toward NNE.

At the time of the morning map 0400, Fontana had a wind NNW 24 m.p.h. gusty and T 61°, D.P. 50, while at 0400 it had been NW 6 m.p.h. T 55°, D.P. 42. The wind increased until 1100 when it was 38 m.p.h. gusty T 71°, D.P. 17, and then decreased until 1700, after which it again increased.

At San Pedro

0800	T. 58°	D.P. 54	R.H. 94	NE 3	30.01
1200	T. 65°	D.P. 59	R.H. 70	NW 15	29.97

On the evening of October 22 the Great Basin HIGH was centered over Idaho 30.64, with a wedge into the Pacific and another south into the Great Basin. The tendencies were +3 over Nevada.

At Fontana the wind was N 30 m.p.h., T 72°, D.P. 24, and the upper winds over the Los Angeles area were NW. The wind at Fontana increased to 46 m.p.h. gusty, at 2300 decreased and again increased at 0200.

At San Pedro the Santa Ana began at about midnight. At 2300 the surface winds for the last hour had averaged NE 17 knots and by 0000 averaged ENE 21 knots, increasing until 0300 October 23, when they averaged

44 knots.

At San Pedro

1600	T 65°	D.P. 57	R.H. 75	W 18	29.90
2000	T 60°	D.P. 55	R.H. 74	NE 7	29.99

On the morning of October 23 the HIGH was centered over Idaho with wedges to NW over the Pacific and to the South through the Great Basin. Tendencies were still +2 in the Great Basin. The gradient in the vicinity of Los Angeles was about $\frac{.25}{100}$ in.hg./mi., with the isobars NE in the Great Basin, but over the coastal mountains they were NW, due to the Barrier Effect. The upper winds at Fresno, Calif., were NE force 7.

At Fontana the wind was NNW 36 m.p.h., T 52°, D.P. 14, and at San Pedro wind was ENE 40 knots.

Burbank, Calif., in the San Fernando Valley, had gotten Foehn winds by 1700 the previous evening, when they became NE 7 m.p.h. with T 71°, D.P. 21. This wind increased at 2000 being NE 26 m.p.h., and at 0000 NE 40 m.p.h. with T 49, D.P. 23. By 0400 the 23d. the wind decreased to NE 18 m.p.h., T 62, D.P. 17.

At San Pedro

0300	T. 62°	D.P. 25	R.H. 24	ENE 46	30.16
1200	T. 68°	D.P. 29	R.H. 23	E 37	30.15

On the evening of October 23 the Great Basin HIGH was 30.68 with wedges as before, but the isobars were now more irregular East of the coastal mountains. The tendencies about -3 at the center. The isobars from Los Angeles were still generally NE and the upper winds were also NE.

The wind at San Pedro had decreased from ENE 44 knots at 0300, until at 1500 it was WSW 10 knots. At Fontana the wind at 1500 was NW

38 m.p.h.; these winds continued from N and NNW, becoming 45 m.p.h. at 1100 October 24, then decreasing to less than 30 m.p.h. after 1400 October 25, when the temperature rose to 85° F with D.P. 35. Winds at San Pedro remained northerly but were less than 15 knots. At Burbank the foehn winds continued until at 1900 when they shifted to E 5 m.p.h., T 69, D.P. 7.

At San Pedro

1600	T. 69	D.P. 31	R.H. 24	W 16	30.10
2000	T. 67	D.P. 31	R.H. 26	E 14	30.11

HIGH Santa Ana of November 1 to 5th, 1935

November 1 P.M. a wave which had been moving E with low pressure centered at L 37 λ 124, was moving into the California coast. There was a HIGH 30.60 in the Gulf of Alaska.

By November 2 A.M. the LOW had moved into the Great Basin, giving a LOW 29.50 in SW Nevada and rain.

November 2 P.M. the LOW had moved to Utah. The upper winds below 8000 ft. showed SSW 100 m.p.h. at Santa Fe, W force 15 m.p.h. along the So. California coast and W light in Oregon and Washington. At levels above 8000 ft., Santa Fe was SW 100 m.p.h., the So. California stations were W 36, and in Oregon and Washington were W and N 35 to 40 m.p.h. The Pp HIGH had extended southward and was now 30.50.

November 3 A.M. the LOW had moved and was centered in New Mexico 29.66, the HIGH was now centered about L 40 λ 135, 30.40.

The winds below 8000 ft. were light except for the warm sector of the LOW over New Mexico where they were SW 40 m.p.h. Above 8000 ft. in So. California, Nevada and Colorado, the winds were W and SW 40 m.p.h., while over Washington and Oregon they were W and NW 40 m.p.h.

The Pc HIGH had moved east to the Marcntime Provinces of Canada, but Pc air was evidently occupying the Great Basin to the NW of the LOW.

Temperatures were much lower than seasonal in the Great Basin.

November 3 P.M. a wedge had started to build south over the Great Basin, the LOW had moved to New Mexico 29.70 and the Pacific HIGH was 30.50 at about L 43 ʎ 137 extending far South.

The winds along the coast were now NE, in the north, becoming NW at San Diego with light winds below 8000 ft. and force 6 above 8000. Behind the LOW its winds were still SW.

November 4 A.M. the Great Basin HIGH was well developed centered over the northern border of Nevada 30.80. The Pacific HIGH was in about the same position as on the previous map but its lower wedge was now NW and SE.

The upper winds below 8000 ft. were light variable, but above 8000 ft. they were force 4 to 6 following the contour of the coast. In the Great Basin they were from N and NW.

November 4 P.M. the Great Basin HIGH was 30.62 at Boise, Idaho. Upper winds now showed divergence from the Great Basin HIGH below 8000 ft. but had become NW force 5 at San Francisco and NW 3 at San Diego with W 6 in New Mexico.

November 5 A.M. the Great Basin HIGH was 30.60 just north of Winnemucca the Pacific HIGH was at L 47 ʎ 137. Upper winds were W 2 to 4 along the Southern California coast NW 7 over Washington and E to 4 from NE and SW along the southern coastal ranges.

At junction during this period the U.S.S. Pennsylvania experienced 30 knot winds from the east off the California coast near Ventura, but no Santa Ana occurred at San Pedro.

The upper winds were ENE and NE during November 4 at San Pedro, but the maximum velocity recorded was 24 m.p.h. at 1530 meters at 0700, which is about half the velocity usually recorded when a High Santa Ana is in progress. (See Fig. 4).

December 1935

On the morning of December 13 the Pacific Polar front was located, WNWasterly ending blind to the south of a Pp HIGH centered at L 35 ⅄ 140, and running up through California, Nevada and Idaho to an occlusion over Juneau. A new front with a deep occlusion was located south of Dutch Harbor and extending westward.

By the morning of December 14 the old Pp front had moved eastward to New Mexico with a LOW over Nebraska, and the occlusion moved eastward to Saskatchewan. The Pp HIGH was feeding a returning Pp air into the Great Basin and building up a HIGH there while the Pacific HIGH was being displaced southward. The new Pp front with a series of occluded waves on it had moved SE and its southern limit was about lat. 35.

December 14 A.M. the Great Basin HIGH was centered north of Winnemucca 30.44 and a LOW 29.82 was centered in the Gulf of Alaska; there was a 30.24 Pacific HIGH about L 34 ⅄ 128 feeding air into the Great Basin.

December 15 A.M. the gradient between Winnemucca and Burbank was 46 in.hg. The Polar Pacific Front had continued to move southward and long occluded waves were wrapped up in the ~~Atlantic~~ Aleutian LOW 29.80 centered south of Dutch Harbor, Alaska. The Pacific HIGH was now 30.20

centered about L 30 / 134 and air from this HIGH had practically ceased feeding into the Great Basin HIGH. On this day no strong Santa Ana winds were reported.

From December 15 A.M. until December 19 the Great Basin HIGH was maintained while occlusions passed across to the north of it. The Pacific HIGH was moved SE and was still evident.

On December 18 a LOW developed south of the Gulf of California and a front oriented itself along the Lower California Peninsula. The gradient resulting by December 19 A.M. between Winnemucca 30.56 and Burbank 29.95 was .61 in.Hg. This increased by the P.M. map to .62 in.Hg. and at 1100 January 19 a Santa Ana began which gave a maximum hourly velocity of 35 knots and lasted 10 hours. (See Fig. 8).

Symbols Figures 2 to 9:

T	Temperature
DP	Dew Point
Δ DP	Difference in dew point AM to PM map
∇ P	Gradient of pressure from Station to Los Angeles or Burbank
Δ T	Difference in temperature from AM to PM map (mark in upper left-hand corner by T gives sky condition if not clear or partly cloudy.
	Lines through sequence show frontal passage
R	Rain
S	Snow
M	Missing

DATE	Los Angeles		Winnemucca			Reno			Tonopah			Modena			
Oct. 1932	T	Bar	T	∇P	ΔT	T	∇P	ΔT	T	∇P	ΔT	T	∇P	ΔT	Isobars
22	56	30 06	40		8	50		0	40		16	56		-4	
	66	02	R 48			50			56			52			
23	56	02	30	20	14	40	14	8	34	-2	12	32	-6	16	
	64	29 90	44	36		48	30		46	12		48	2		NE
24	54	96	16	54	28	28	46	20	28	28	16	32	14	6	NE Low developed
	76	98	44	54		48	48		42	32		38	22		NE
25	60	30 14	18	44	34	24	40	32	30	28	20	26	20	18	
	70	10	52	32		56	32		50	M		44	20		

Fig 2

Highest Hourly velocity 31 Kts. max. gusts 46 Kts.
began 1400 Oct 24 Duration 11 hours

19 Nov 1930	46	30 15	14	29	18	18	25	20	12	21	16				
19	57	17	32	29		38	25		28	25					NE
20	46	24	16	38	18	20	32	20	18	28	14				E
	62	24	34	38		40	32		32	28					E
21	53	27	18	39	20	22	39	20	24	29	10				E Low develops
	68	13	38	53		42	47		34	37					ESE
22	61	08	34	54		42	44		36	32					
	57	04	28	48		26	44		24	38					SSE

Highest Hourly velocity 35 Kts.
began 2000 21 Nov

	Burbank			Winnemucca				Reno				Tonopah				Daggett				Las Vegas				
DATE	T	DP	Bar	T	DP	ΔDP	∇P	ΔT	T	DP	ΔDP	∇P	ΔT	T	DP	ΔDP	∇P	ΔT	T	DP	ΔDP	∇P	ΔT	Isobars
Oct 1935																								
16	47	40	30 00	34.6	35	-6	28	16	27	25	2	26	27	38	29	-3		8	44	38	-8	10	25	52 26 -6 18	
	65	31	01	51	29		39		54	27		37		46	26		25		69	26		15		70 20 1	
17	70	29	10	25	23	+1	46	31	23	20	3	46	37	34	22	+1	30	20	51	21	4	20	19	56 24 -3 15	E
	80	24	06	56	24		44		60	23		43		54	23		28		70	24		18		71 21 25	E
18	71	25	02	36	26	+2	44	27	23	20	-2	47	42	39	23	-3	30	20	49	27	8	16	24	63 20 +8 16	E
	83	32	29 95	64	28		25		65	18		26		59	20		17		73	35		5		79 28	
19	60	35	92	27	26	+8	14	34	22	18	9	17	46	51	20	0	2	12	58	43	-11	2	22	64 38 +2 5 13
	73	56	89	61	34		7		68	29		4		63	20		-3		80	32		-8		77 40 9	
20	58	55	93	31	27	-5	15	23	29	27	-5	10	32	44	26	-8	-7	18	51	36	-1	-5	27	47 35 -2 3 30
	65	55	89	54	22		-5		61	22		1		62	18		-7		78	35		-7		77 33 -5 front pass
21	55	52	95	35	25	-10	15	8	36	21	0	15	15	32	12	-7	-9	10	63	36	-4	-10	10	49 25 -7 -9 22
	64	53	92	44	15		28		51	21		26		42	5		18		73	32		-3		71 18 5
22	45	39	98	22	16	+1	38	17	14	10	4	41	30	28	6	+7	22	9	45	27	-7	12	18	52 17 -2 22 10 ENE
	78	24	93	39	17		65		44	14		65		37	13		41		63	14		24		62 15 30 ENE
23	61	13	17	13	12	-2	67	34.0	26			54		22	9	-1	43	22	45	18	-4	28	16	50 15 -9 37 13
	73	20	11	47	10		47		48	12		45		44	8		35		61	14		24		63 6 11 NE

Highest Hourly velocity 44 Kts. began 0000 Oct 23 duration 13 hrs.

Fig. 3

Date Nov 1935	Burbank T	DP	Baro.		Winnemucca T	DP	ΔDP	∇P	ΔT	Reno T	DP	∇P	ΔT	Tonopah T	DP	∇P	ΔT	Daggett T	DP	∇P	ΔT	Las Vegas T	DP	∇P	ΔT	
2	48	47	29	93	25	24	0	-19	0	29	29	-15	-5	32	23	-5	-37	2	58	33	1	-13	-5	62	22	-3	-12	-2	
	56	53		95	25	24		-1		34		-7		34	18		-21		53	34		-11		60	19		-19		front pass
3	40	30		99	16	15	1	M	2	18		15	1	18	14	2	-3	9	42	38	-10	-6	12	36	15	-7	-4	0	
	55	42	30	01	18	16		33		17	7	35		27	16		13		54	28		3		54	8		7		
4	34	29		09	1	0	17	47	22	9	7	48	11	14	7	5	27	9	30	17	4	14	22	41	13	1	22	10	NE
	64	31		05	23	17		52		20		51		33	12		39		52	21		17		51	14		29		E
5	43	18		06	6	6	16	52	20	13	10	50	11	18	10	5	28	24	31	12	13	20	26	31	15	3	30	27	E
	69	24	29	97	26	22		49		24	18	53		42	15		25		57	25		17		58	18		24		E
6	38	16	30	02	9	9	21	44	24	6	1	50	28	30	17	4	18	18	36	7	24	9	28	58	18	7	21	7	
	70	29	29	95	33	30		43		34	28	19		48	21		17		64	31		10		65	25		18		ESE

No Santa Ana

25	46	46	30	06	28			26	10																			
	57	52		05	38			27																				
26	40	40		16	18			26	20																			
	52	43		12	38			30																				
27	44	44		19	30			29	12																			
	58	43		20	42			32																				
28	50	32		23	20			47	22																			
	74	41		17	42			39																				
29	52	29		15	20			39																				

No Santa Ana

4 (1.9.)

DATE	Los Angeles		Winnemucca			Reno			Tonopah			Daggett	Las Vegas	Isobars
DEC 1929	T	DP Bar	T	DP	VP ΔT	T	DP	VP ΔT	T	DP	VP ΔT			
18	64	30 04	34		20 14	42		20 14	40		10 8			
	76	9 96	48		18	56		12	48		12			Low to S
19	62	29 86	46		18 -2	48		14 -2	42		8 0			
	71	74	44		40	46		25	42		10			NE
20	64	92	32		40 8	32		38 12	26		26 10			Low to SE
	70	30 08	38		34	44		26	36		20			NE

Highest Hourly velocity 21 Kts Duration 11 hours
began 0700 Dec 20

DEC 1929														
25	62	30 17	28	3	18	48	-3	2	36	5	2			
	66	09	46	7		50	-1		38	1				
26	55	10	28	28	10	28	28	16	28	16	10			NE
	69	08	38	36		44	30		38	20				ENE
27	58	30 14	16	32	22	26		18	32	16	6			Low developed
	70	12	38	30		44	32		38	22				E
28	63	12	14	44	24	22	42	10	36	28	6			ESE
	78	04	38	50		42	40		42	32				
	63	05	18	41										

Highest Hourly velocity 22 Kts Duration 12 hours
began 1100 Dec 28

fig 5

Fig 9

DATE DEC 1935	Burbank T	DP	BAR.	Winnemucca T	DP	ΔDP	∇P	ΔT	Reno T	DP	ΔDP	∇P	ΔT	Tonopah T	DP	∇P	ΔT	Daggett T	DP	∇P	ΔT	Las Vegas T	DP	∇P	ΔT	Isobars
13	46	25	29 93	22			23	12	18	16		33	14	20	08	15	8	34	24	11	16	45	19	3		N&S
	62	38	94	30			34		32			34		28		28		50	21	19		M		8		NE
14	44	22	30 06	14	14	10	32	14	16	13	14	35	16	17	12	28	11	24	13	22	23	32	13	20	15	NW
	65	28	02	28	24		40		32	29		39		28	13	30		47	20	22		47	18	32		E
15	40	18	08	26	13	7	46	12	15	14	12	36	12	20	16	22	9	30	14	16	18	25	3	26	24	E
	65	28	00	38	20		28		27	26				29	14	30		48	17	20		49	13	26		
16	42	16	08	11	10	14	38	17	18	15	7	42	7	18	15	28	13	26	10	18	12	35	8	28	9	E
	65	25	07	28	24		41		25	22		43		31	15	33		42	29	22		44	10	29		
17	46	13	08	12	11	7	40	22	9	8	22		21	26	18	26	12	24	5	25	25	25	0	35	20	ESE
	66	25	00	34	18		34		32	30		38		38	25	22		49	19	21		45	12	30		ESE
18	38	13	04	14	11	7	32	20	11	10	13	37	24	34	19	12	5	20	4	17	32	20	2	32	31	ESE
	66	19	29 98	39	18		44		35	23		47		39	8	24		52	15	20		51	12	30		
19	65	15	95	6	4	17	61	28	11	9	14	63	27	24	10	39	12	25	12	27	27	32	3	6	23	ESE
	70	12	88	34	21		62		38	23		63		36	13	44		52	19	24		55	9	33		SE
20	56	40	99	22			51		10	8		47		28		21		49	37	15		48	35	29		SE
							32					38														

Highest hourly velocity 28 Kts began 1100 19 Dec. Duration 10 hours

DEC 19 1930																										
20				0			38	22	16			28	14	12		30										
	60		08	22			48		30			34		26		28										Low to SE
21	48		16	8			46	16	14			36	18	14		28	10									
	60		16	24			46		32			34		24		36										

Highest hourly velocity 23 Kts began 1030 20 Jan. Duration 24 hours

DATE	Los Angeles		Winnemucca			Reno			Tonopah			
JAN 1933	T	Bar	T	∇P	ΔT	T	∇P	ΔT	T	∇P	ΔT	Isobars
6	54	30 02	26	28	16	28	32	16	32	10	10	
	52	.10	42	30		44	30		42	6		
7	60	12	22	32		26	28	20	34	16		
	68	12	M			46	26		M			
8	54	16	20	30	18	24	26	28	36	16	8	
	66	14	38	32		52	22		44	16		
9	62	14	18	20	22	26	16	28	40	8	4	
	68	02	40	18		54	2		44	0		KF Pass
10	52	29 98	20	34	10	24	30	12	26	12	2	ENE
	58	94	30	36		36	50		28	36		NE
11	54	30 20	8	50	24	22	40	16	14	40	12	NE
	62	24	32	40		38	28		28	36		E
12	54	22	12	32	24	18	30	26	22	32	14	E
	64	18	36	40		44	32		36	28		
13	56	18	14	42	20	22	38	28	30	24	8	
	70	14	34	42		48	30		38	22		

Highest Hourly velocity 54 Kts began 0000 Jan. 11 Duration 18 hours

JAN 20	48	30 00	28	12	4	28	14	4	20	2	4	
1932	56	05	32	27		32	23		24	17		
21	48	16	8	32	30	20	28	10	12	22	10	
	58	20	28	28		30	16		22	2		
22	46	26	8	22	16	20	16	12	18	4	6	
	56	26	24	24		32	22		24	12		
23	46	26	0	50	16	26	34	6	10	24	8	
	64	28	16	48		32	30		18	32		
24	44	34	0	44		12	30		12	26		

Highest Hourly velocity 26Kts began 0800 Jan. 23 Duration 11 hours

f19 7

DATE Feb 1936	Burbank T	DP		P	Winnemucca T	DP	∇P	ΔT	RENO T	DP	ΔDP	∇P	ΔT	Tonopah T	DP	∇P	ΔT	Daggett T	DP	ΔDP	∇P	ΔT	Las Vegas T	DP	ΔDP	∇P	ΔT	Isobars
26	41	34	30	28	37	26	12	14	24	20	12	20	28	28		6	20	37	32	-9	12	26	38	19	4	5	28	
	65	40		20	46		10		52	32		17		48		8		63	23		10		66	23		5		
27	44	32		21	30	24	9	20	25	24	2	14	29	34		1	18	36	29	-1	11	30	28	12	11	7	39	
	72	56		09	50		1		54	26		5		52		-7		66	28		5		69	23		2		
28	42	35		04	36	34	16	12	36	32		19	14	40		-4	8	44	25	-1	5	25	30	14	9	4	39	
	68	44	9	96	48		36		50			34		48		16		69	24		8		69	21		6		
29	68	33		05	28	26	45	28	29	28	7	42	31	28		31	26	53	32	-4	16	18	48	28	-6	19	25	E
	81	32		07	56		37		60	35		38		52		25		71	28		12		73	22		8		
Mar 1	56	29		04	28	28	40	26	29	27	5	42	31	34		20	18	48	28	-1	13	26	53	21	3	10	21	Low to S
	84	27	9	91	54		45		50	32		43		52		27		74	27		11		74	24		4		"
2	73	30		90	34	30	46	24	28	27	7	42	34	36		30	18	53	34	4	19	22	56	29	-7	19	17	"ESE
	84	36		87	58		28		66	34		22		54		18		75	38		10		73	32		6		
Mar 1933	No Data from San Pedro																											
2	46		30	05	26		5	26	36			1	16	36		-5	8											
	57			03	52		-5		52			-3		44		-1												
3	47			09	38		1	0	36			3	8	36		-7	4											Low to SE N to S
	73		30	01	38		31		44			18		40		12												NE
4	56			02	20		50	16	30			38	16	24		32	12											NE
	80			02	36		50		46			36		36		34												NE

Highest Hourly Velocity 26 Kts Began 2000 4 Mar Duration 14 hours

DATE	Los Angeles		Winnemucca			Reno			Tonopah			
Dec 1934	T DP	P	T DP	∇P	ΔT	T DP	∇P	ΔT	T DP	∇P	ΔT	isobars
1	50	2995	8	19	22	24	23	10	24	-1	2	NNE
	59	97	30	34		34	32		26	22		
2	51	3019	8	33	18	22	25	10	16	25	12	
	66	28	26	38		32	24		28	22		ENE
3	49	32	12	32	18	16	32	24	20	20	14	
	64	18	30	30		40	30		34	20		ESE
4	54	06	24	38	8	26	34	10	26	12	4	Low to S
	66	29 88	32	58		36	50		30	30		SE
5	58	90	24	62	8	26	56	12	20	36	12	E
	62	95	32	51		38	41		32	29		
6	59	95	26	48	10	20	46	22	26	34	8	
	64	3001	36	57		42	43		34	35		1

Highest Hourly velocity 34 Kts?

Fig 9

6 Pressure Gradients

In making this study the reference pressure gradient is taken as that from Winnemucca, Nevada to the Weather Bureau Station in Los Angeles for cases before 1935, and for cases during 1935 to the Weather Bureau Station in Burbank.

It would be better to consider the gradient to San Pedro Harbor but exact pressures are not available as on ships of the Navy pressures are recorded at 0000, 1200, 1500, and 2000, Local Standard Time, while the weather map readings are for 0300 and 2000 G.S.T.

Winnemucca, 400 miles NNW of Los Angeles, was chosen as the reference station in the Great Basin because most of the high pressure areas seem to be centered either near Winnemucca or north of it. Daggett about 100 miles ENE of Los Angeles in the Great Basin, may be a better station for reference than Winnemucca, as it is not at such a high elevation and is nearer San Pedro. However, Daggett was not available on maps studied until 1935.

With stations at Daggett, Las Vegas, Palmdale, Independence, and other places in the Great Basin near the Los Angeles area, studies of pressure gradients to such stations should prove of great value.

These stations have the advantage of being at lower levels and hence less subject to reduction errors than Winnemucca, Tonopah and Modena. They will show a gradient which will act more directly because nearer, as the gradient which acts to force the air out to the Los Angeles Basin is that acting on the western side of the Sierra Madres, and hence should be more significant than that from some more distant point.

Santa Anas have occurred giving average hourly velocities of 30 knots ENE with a gradient of as low as .40 in.hg. to Winnemucca. In this case, December 20, 1929 (Fig. 5), the Santa Ana lasted 11 hours but was accompanied by a LOW which formed south of San Diego and moved East to Arizona.

The highest gradient found occurred during the Santa Ana of October 23, 1935, when it reached .65 in.hg. to Winnemucca (Fig. 3). This gave ENE winds whose highest hourly average was 44 knots.

0500 October 22 the gradient to Winnemucca was .30 in.hg. and .12 in.hg. to Daggett when the Santa Ana winds started at Fontana. At 0400 the wind had been W 4 m.p.h., T 55, D.P. 42, by 0500 the wind was NNW 24 m.p.h., T 61 and D.P. 30. The Santa Ana did not start at San Pedro until midnight of the same day, with a gradient of .65 from Winnemucca and .24 from Daggett.

On October 17 A.M., 1935, the gradient reached .46 in.hg. to Winnemucca and .20 in.hg. to Daggett. However, no Santa Ana or ENE winds occurred in the Harbor during this night. The winds were NE 21 knots at 2200 the 16th at 2100 they had only averaged NE 9 at 2500 they had averaged 12 knots. During this night the dew point at San Pedro had dropped from 52 at 2000 the 16th to 34 the next morning.

On December 15, 1935 at 0500 the gradient also reached .46 in.hg. to Winnemucca and .16 to Daggett. However, on the 14th both A.M. and P.M. maps showed .32 in.hg. to Daggett and .32 and .40 to Winnemucca. This gradient did not produce a Santa Ana.

During the period November 4-5, 1935, the gradient amounted to .32 in.hg. from Winnemucca but no Santa Ana winds reached the surface at San Pedro and the upper winds were not as strong as on other occasions

when there was even less gradient.

The November 1935 case shows a higher gradient than any other case studied, which failed to produce a Santa Ana. The big difference in this case appears to be that the air which formed the HIGH flowed around a LOW which moved into the Great Basin far south of the path of most LOWS. The synoptic situation shows that We must have crossed the Rocky Mountains and entered the Great Basin. The low temperatures which followed the passage of the LOW tend to confirm this.

Lapse rates in the winter are stable or show a considerable inversion to high levels. Such air generally fails to cross the Rocky Mountains because of its stability, and for the same reason it would have difficulty overcoming mountain passes of the Coastal Range.

Complete data are not available for the period March 27 to February 2, 1936, when a gradient of .49 in.hg. on February 29 P.M. failed to even dissipate the fog at the Harbor, while causing a 53 m.p.h. wind at Fontana. However, on March 1 or 2 the same gradient caused winds of about 34 knots at the Harbor.

From these examples and ∇ p in Figs. 2-9, it can be seen that gradient from a reference station in the Great Basin is not the controlling factor in this problem.

One very important factor which plays a part in the gradient producing Santa Ana winds is the gradient to the west of San Pedro. It appears significant that in cases where there is a separate HIGH in the Pacific or one connected by a saddle with that in the Great Basin, Santa Ana winds do not easily reach the surface at San Pedro. A careful analysis of the weather maps of October 17-18, 1935, December 15-16, 1935, shows this distribution of pressure.

It would be difficult to get an accurate value of the gradient from the Pacific or to forecast that gradient at present; however, it must be considered in this problem. With accurate observations from San Nicolas Island and more accurate pressure observations from ship stations, work can be done in this line at some future time.

Until a study of Santa Ana winds is made using pressure maps drawn for pressures reduced or raised to some level as the 5000 ft. level, it will be problematical what reduction errors enter into the pressures reported by the Great Basin stations.

The low temperatures during the November 1935 case discussed may be the explanation for the apparent failure of the development of a Santa Ana with such a gradient as .52 in hg. from Winnemucca. With low temperature the reduction errors from the high level stations might be considerable.

Temperatures

Early in this study of Santa Ana winds, an attempt was made to correlate temperature differences between Great Basin stations and Los Angeles, with some other factor such as ∇p which influenced the winds, but no success was apparent along this line of endeavor.

Conditions of low humidity often set in at San Pedro without being followed by Santa Ana winds. When this happens temperature rises about 10° F above normal for the season. At other times fog may be present until just before strong Santa Ana winds arrive at the surface in the Harbor. With these different temperature conditions, combined with irregularities and the fundamental unconservativeness of temperature, no recognisable correlation could well be expected.

Study of dew point difference offers a possibility of better results because the dew point of the air is more conservative than temperature; however Weather Bureau stations did not report dew points until recently.

An attempt to study the relative stability of the air which causes high Santa Anas and those which reach the surface must be made by indirect methods, as Seattle and Spokane are prevented by weather from making regular aerograph ascents, and there are no stations in the Great Basin which make them.

According to H. C. Willett "American Air Mass Properties", Pp air with a short history over the Pacific has an almost adiabatic lapse rate in the lower two kilometers and that with a longer trajectory over the ocean has a more stable lapse rate at Seattle. In the Great Basin it would be expected that Pp air would retain somewhat similar lapse rates. The October 1936 case seems to bear this out in many respects. Δ T is greater with older Pp air and T is lower, and in general the Pp of more recent Polar origin seems to be more unstable.

Figs. 2 to 9 have a column Δ T which represents the change in temperature at the station from 0300 L.S.T. to 2000 L.S.T. This difference can be considered as a measure of the stability of the air above the station if allowances are made for change of air mass or differences of cloud cover or wind velocity. Fortunately the air in the Great Basin is relatively cloudless and wind velocities seldom exceed force 3. In the figures referred to, cloud cover is indicated by the dots • meaning cloudy, and ◔ partly cloudy. Frontal passages are indicated by a line through the tabulation.

If the lapse rate at a station is adiabatic small diurnal difference in temperature would be expected as the heat would be carried aloft rapidly by convection. If the lapse rate were stable considerable diurnal change in temperature would result.

There are other factors than the three mentioned which would influence the difference of temperature, but they cannot be allowed for at this time.

If the factor of difference of temperature ΔT is considered for cases where complete readings for several days are available, e.g. October, November, December 1935, January 1933, October 1932, February 1936, the difference is found to increase until a new frontal passage is experienced at all stations except Tonopah. This would show that the air is being stabilized.

In the October 1935 case, the air present before the front passage about October 19 P.M. would appear to be more stable and warmer than that which followed.

In the November 4, 1935 case, the air entered the Great Basin by November 2, crossing the Rocky Mountains under the influence of a LOW which passed from the Pacific to Texas. How such air would be modified is problematical but the turbulence caused by such a passage should tend to bring heat down and make the air less stable.

The air in winter over the Plain States has an inversion which extends to very high levels and is very dry. After a passage over the Rockies into the Great Basin, this inversion will probably not be entirely destroyed.

The factor Δ T in Fig. 8 shows the air to be relatively stable and Δ DP or change in dew point during the day shows a considerable increase. This can also be interpreted as meaning stable air for the diurnal heating would tend to carry the moisture away from the earth, thus decreasing the dew point during the day. As dew point is a function both of temperature and relative humidity, a considerable loss of moisture would tend to decrease the dew point even though the temperature increased.

Comparison of these factors, dew point, temperature, Δ DP and Δ T in the October 1935 and November 1935 cases will illustrate this point. The decrease in dew point from morning observation to the next morning during the time an unstable air mass is over the station can be noticed. During the period October 21, 1935 to October 23, 1935, instability can be noticed and the opposite effect during the other periods in October 1935 and November 1935.

Velocity Gradient Curve for Santa Ana

The curve, Fig. 10, shows the correlation between highest average hourly wind velocity on ships in San Pedro Harbor and pressure gradient from Winnemucca, Nevada, to the vicinity of the Harbor.

The upper part of the curve is problematical as only three points are available and these show poor correlation. It is thought that the January 1935 case shows a high velocity because this case followed a frontal passage. The December 1935 case was caused by the circulation between a LOW to the south and a HIGH in the Great Basin.

When enough cases are available for study, it will probably be found that curves for pure pressure gradient, development of LOW circulations and combinations of these factors with relative instability due to type of air mass and frontal effects can also be found.

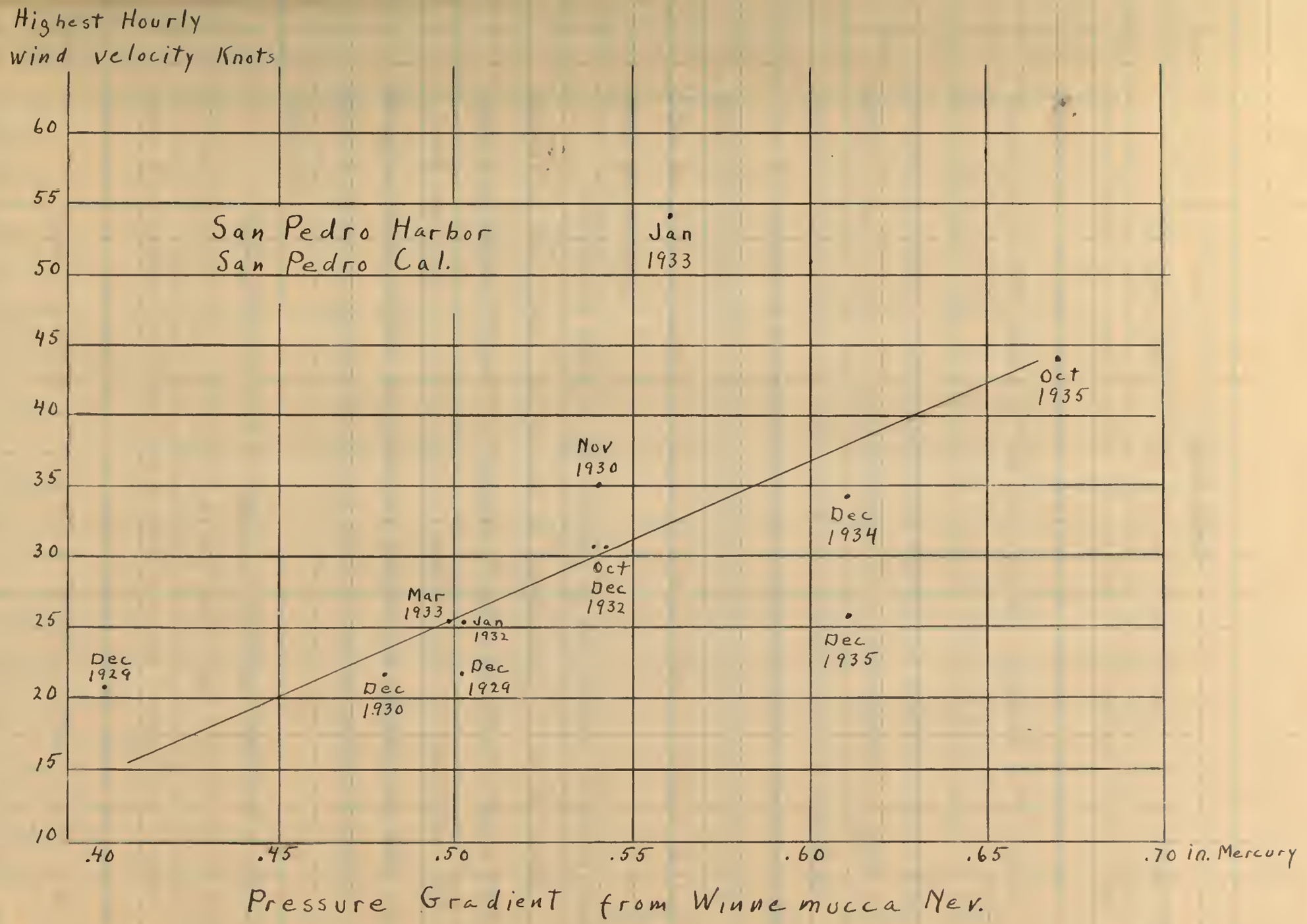

Highest Hourly
wind velocity Knots
60
55
50
45
40
35
30
25
20
15
10
San Pedro Harbor
San Pedro Cal.
Jan
1933
Oct
1935
Nov
1930
Dec
1934
Oct
Dec
1932
Mar
1933
Jan
1932
Dec
1935
Dec
1929
Dec
1930
Dec
1929
.40
.45
.50
.55
.60
.65
.70 in. Mercury
Pressure Gradient from Winnemucca Nev.

fig 10

Upper Winds

The upper winds records at San Pedro available for October 1935 show an velocities over 3 m/sec. in the lower 1000 meters before 1445, October 22. At 2055 the surface wind was NE 6 m.p.s., increasing to 17.4 m.p.s. at 612 meters, by 2245 the wind had increased to 21 m.p.s., or 47 miles per hour at 990 meters where it had been 13.3 m.p.s. on the previous sounding. This considerable increase in velocity in the upper air in a short period is characteristic of the development of Santa Ana winds, in those cases for which upper air observations are available.

As far as the writer can see at this time, from the upper wind observations available, the upper winds at San Pedro offer no criteria which can give definite indications of when a Santa Ana will or will not reach the surface.

The upper winds in the vicinity of Los Angeles, in cases where there is a Great Basin HIGH without an accompanying LOW to the south, shift from between NW and N to between NE and E in 12 to 24 hours before a Santa Ana occurs. In some cases it appears that the velocities show 20 m./s. or more before the Santa Ana reaches the surface, but this warning cannot be counted on because haze or fog may prevent balloon soundings.

Other stations such as Jacumba or Sandberg have been tried as key stations for upper air indicators for Santa Anas. So far no stations upper air observations alone have proved a key to forecasting. Upper winds must be correlated with the other factors which enter the problem.

Upper winds must go into the NE quadrant before a Santa Ana occurs but they often do this without the occurrence of a Santa Ana. When records for upper winds are available for these conditions over a

long period of time, some correlation between the upper wind observations may appear.

Aerology

Records of balloon soundings over the entire area affected, and of aerograph soundings from San Diego give an interesting picture of the conditions of the air in the vicinity of San Pedro. Unfortunately no aerograph ascents are available in the Great Basin or in the Los Angeles Basin, but for a number of years the Naval Air Station at San Diego has made these ascents.

During the period October 15 to 24 a remarkably complete record of the upper air at San Diego is available as ascents were made twice daily, weather permitting. Sketches 11 to 15 show θE, Equivalent Potential Temperature, plotted against height for this period. The drop in θE shown by the Fig. 12 for October 23, 1935, and that of Fig. 13 for October 17, 1935, appear typical for Santa Ana conditions. The low θE extending to the surface, as in Fig. 12, only in well developed cases

When the ascents are plotted on the adiabatic chart, a marked drop in θ, Potential Temperature, is shown.

San Diego is about 100 miles from San Pedro, so in order to get a picture of lapse rate conditions at San Pedro during a Santa Ana a point was located on the adiabatic chart (Figs. 16-17) using height of Mt. Wilson and temperature at 0400. This was joined with a point plotted by using temperature and pressure at San Pedro Harbor at 0800. The resulting lapse rate shows convectively unstable air while normally the lapse rate between these two points is broken by a sharp inversion giving a smoothed lapse rate almost isothermal. The corresponding curve for San Diego on this morning showed a lapse rate corresponding very closely

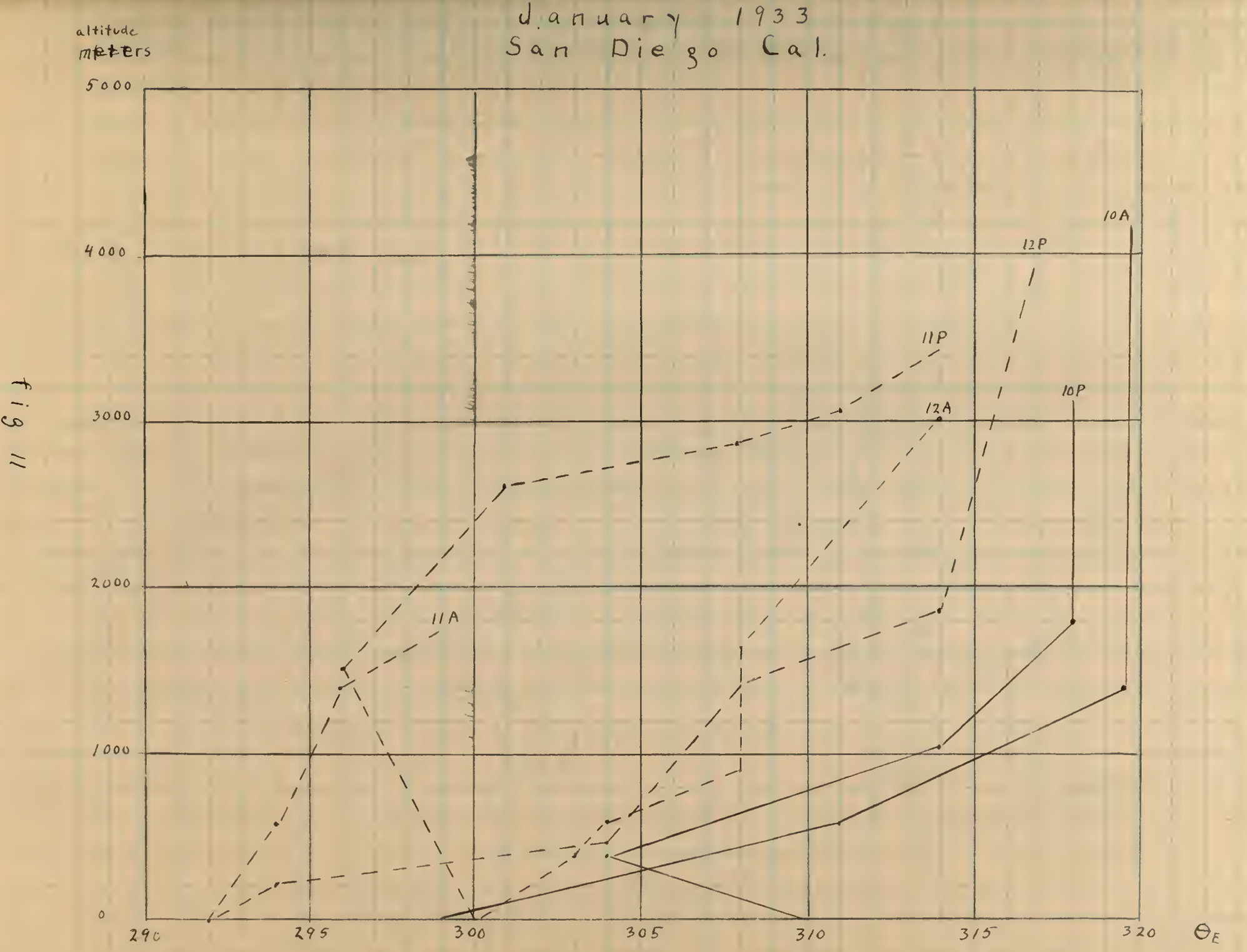

January 1933
San Diego Cal.
altitude
meters
5000
4000
3000
2000
1000
0
290
295
300
305
310
315
320
Θ_E
10A
12P
11P
10P
12A
11A

Fig 11

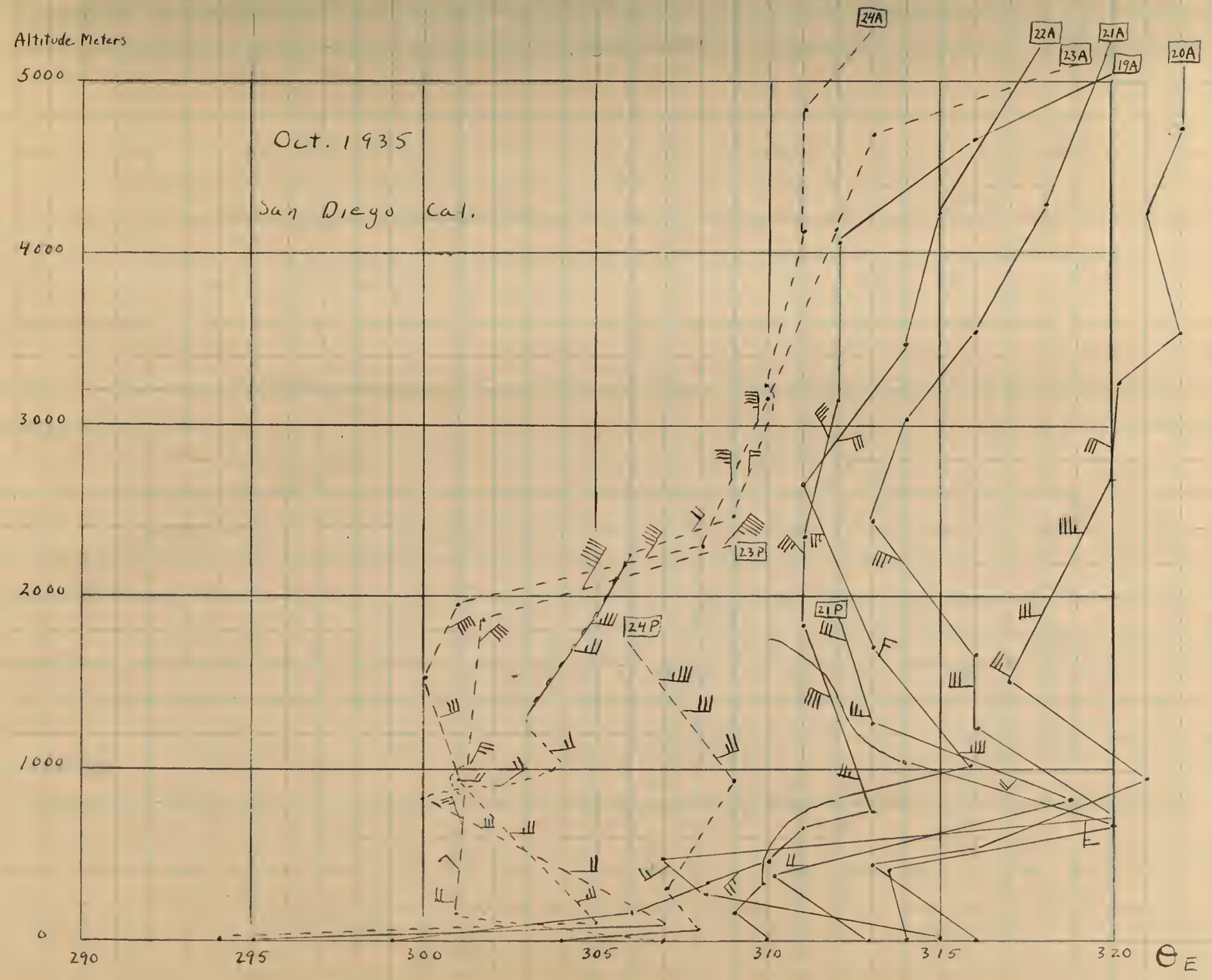

Altitude Meters
5000
4000
3000
2000
1000
0
Oct. 1935
San Diego Cal.
24A
22A
23A
21A
19A
20A
23P
24P
21P
290
295
300
305
310
315
320
θE

fig 12

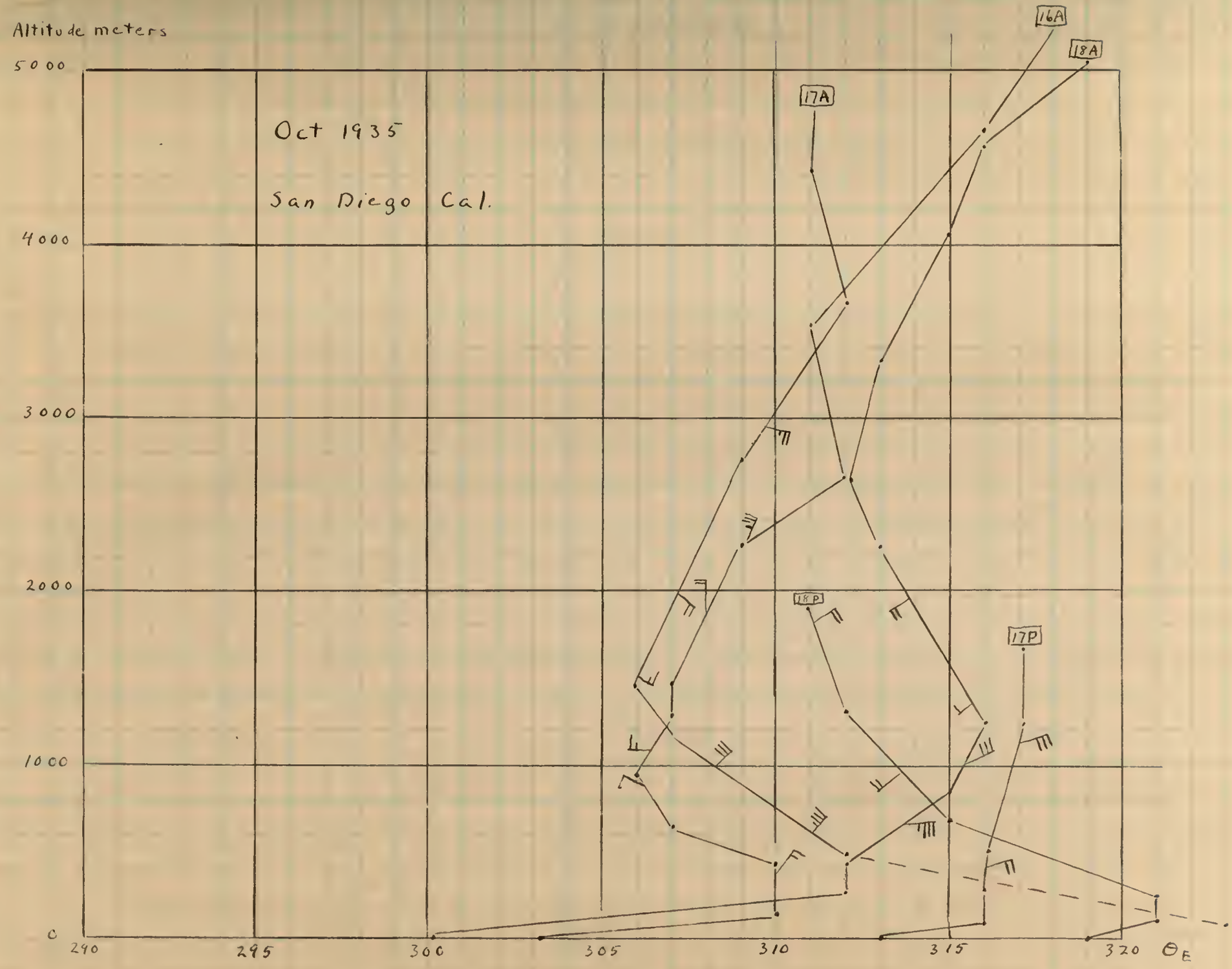

Altitude meters
5000
4000
3000
2000
1000
0
Oct 1935
San Diego Cal.
16A
18A
17A
18P
17P
240
295
300
305
310
315
320
Θ_E

fig 13

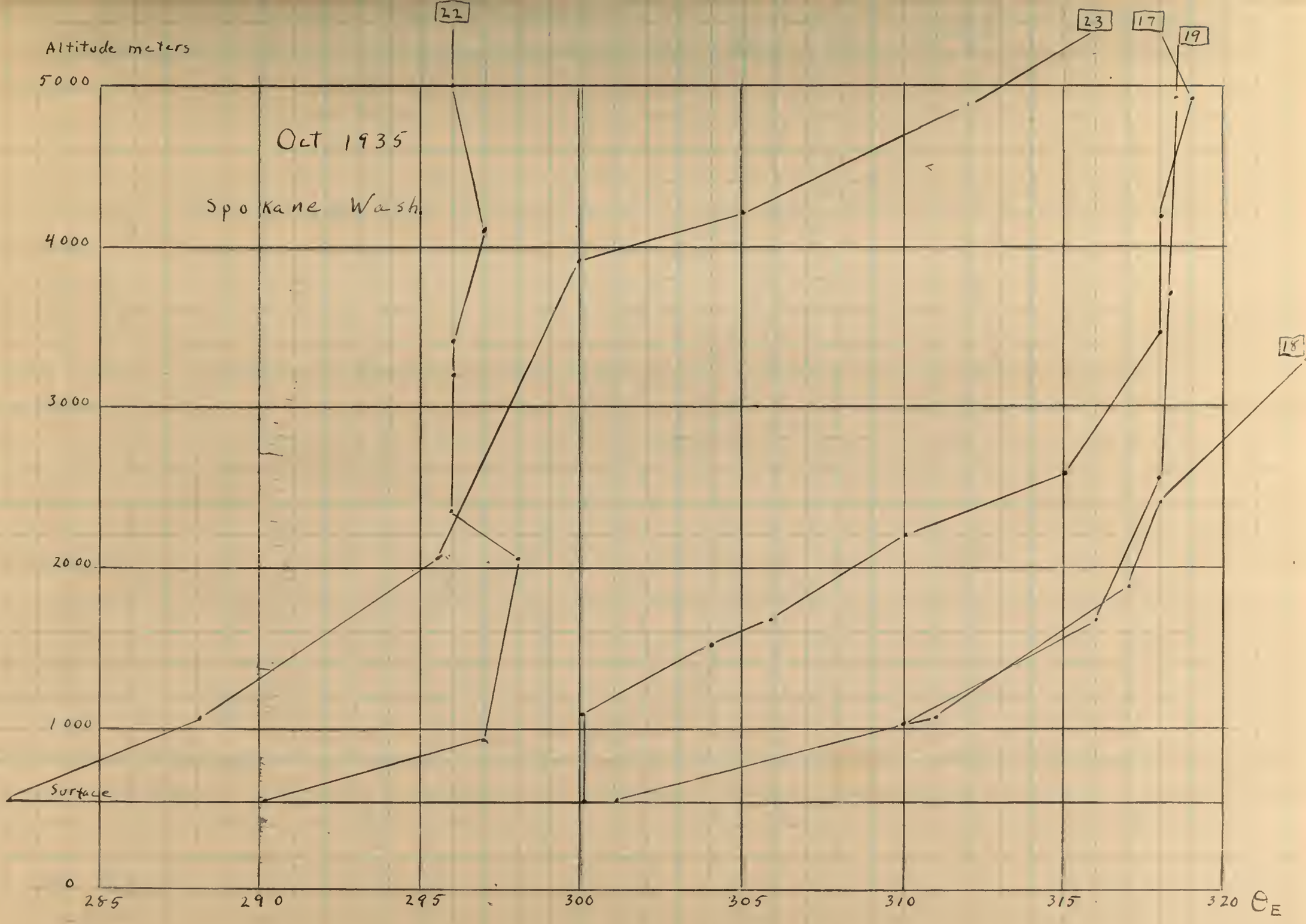

Altitude meters
5000
4000
3000
2000
1000
Surface
0
Oct 1935
Spokane Wash.
22
23
17
19
18
285
290
295
300
305
310
315
320
θ_E

Fig 14

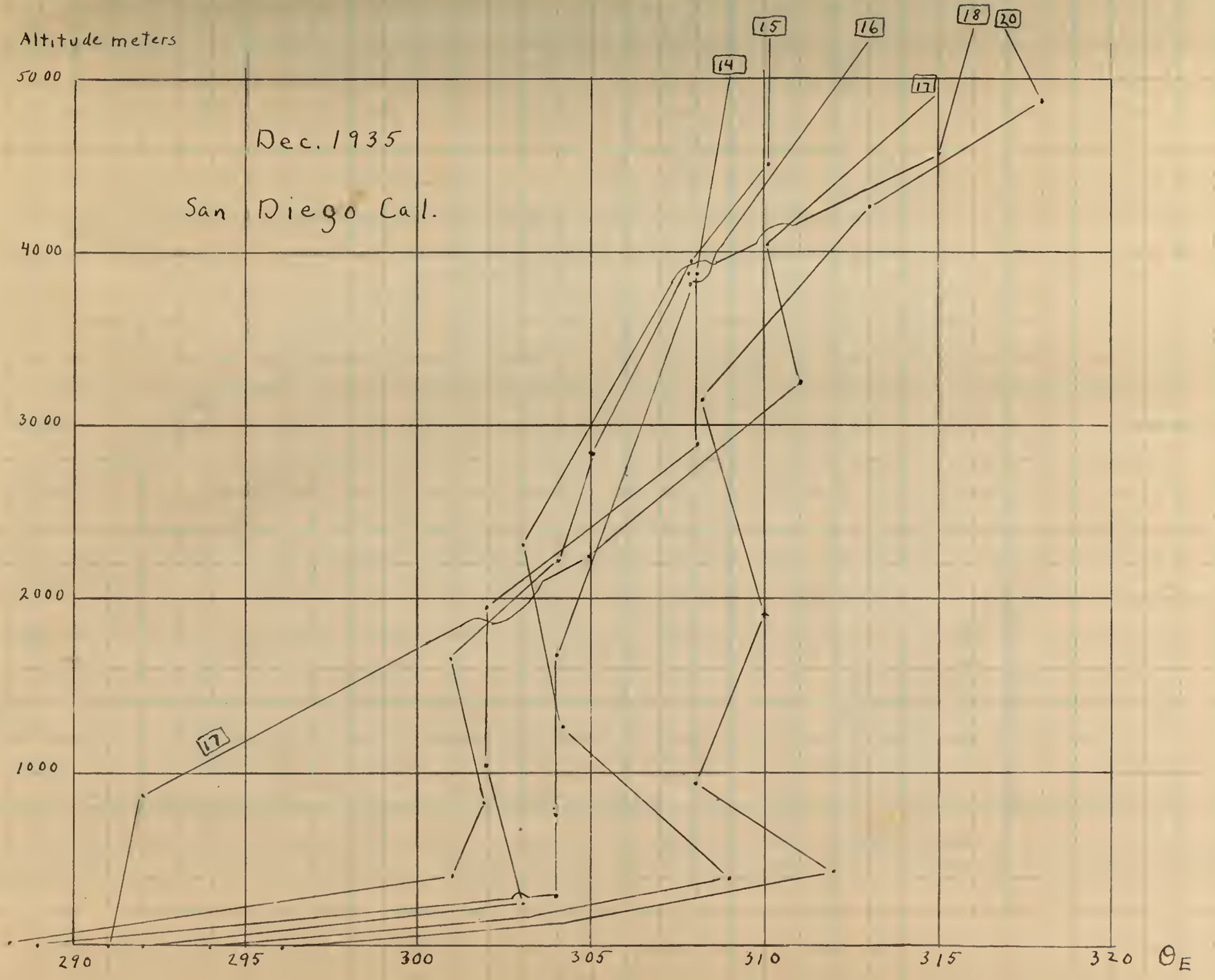

Altitude meters
5000
4000
3000
2000
1000
Dec. 1935
San Diego Cal.
14
15
16
17
18
20
17
290
295
300
305
310
315
320
θ_E

Fig 15

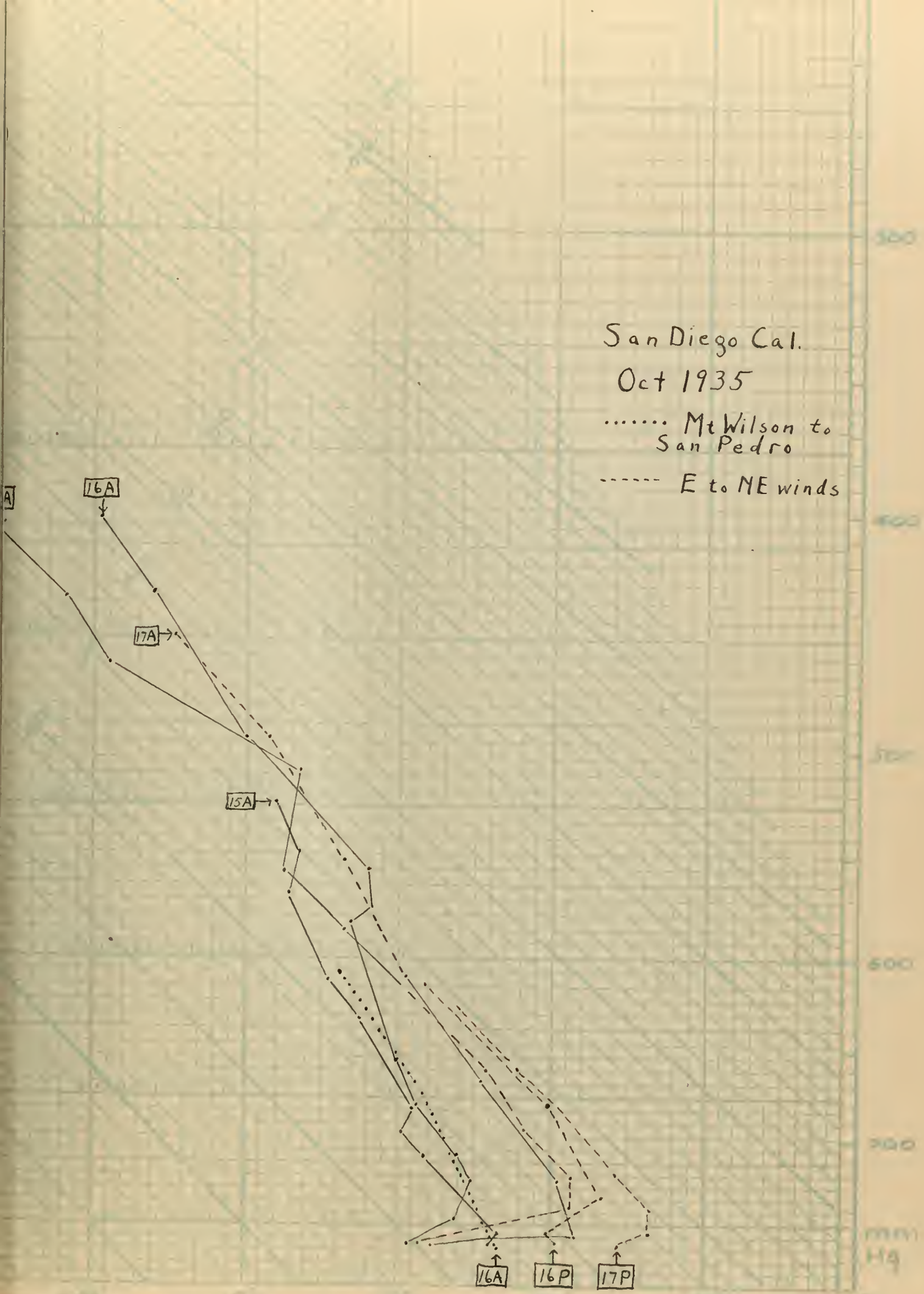

San Diego Cal.
Oct 1935
..... Mt Wilson to San Pedro
----- E to NE winds
16A
17A
15A
16A
16P
17P

fig. 17

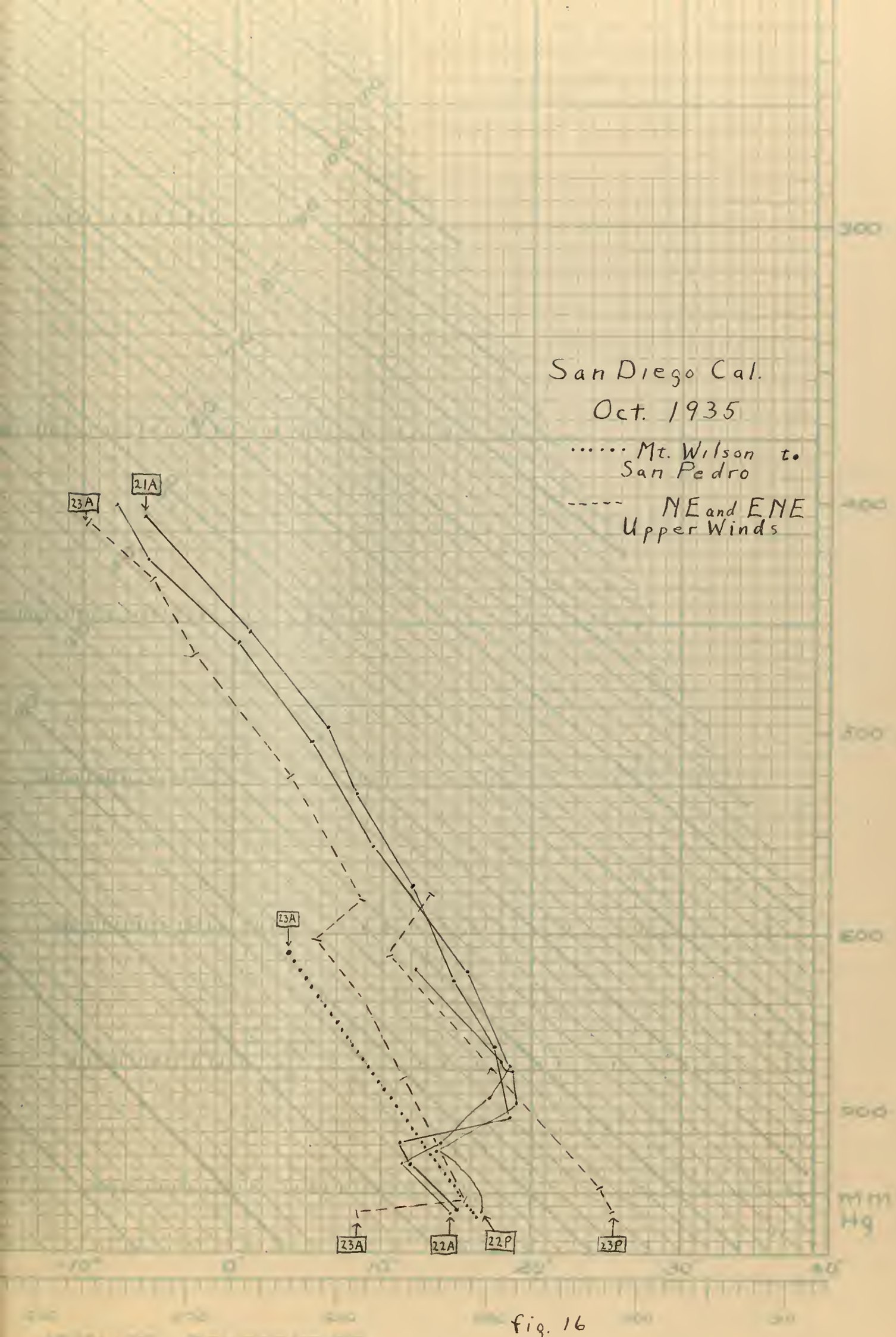
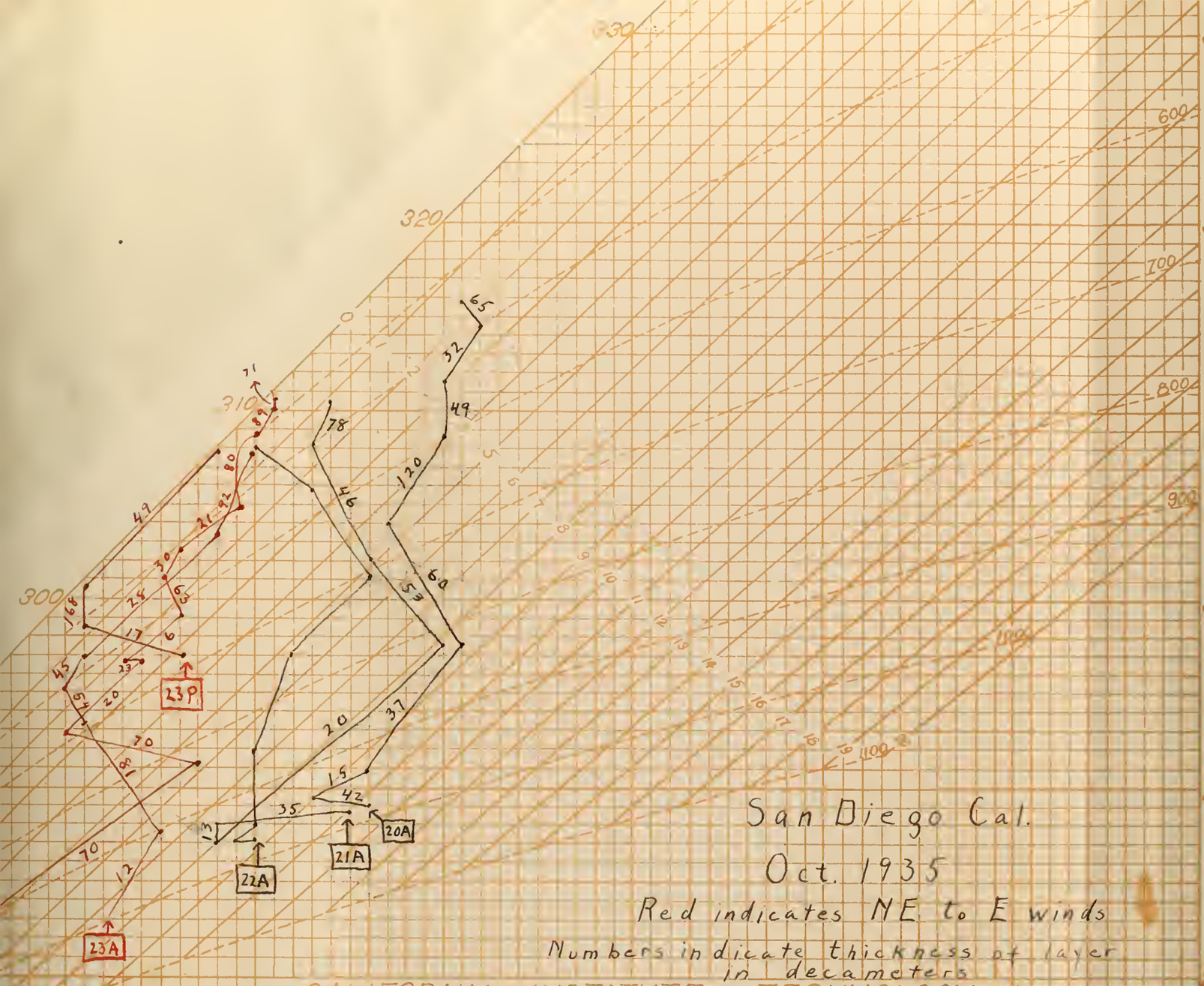

San Diego Cal.
Oct. 1935
..... Mt. Wilson to San Pedro
----- NE and ENE Upper Winds
23A
21A
23A
23A
22A
22P
23P
300
400
500
600
700
mm Hg
ABSOLUTE TEMPERATURE

fig. 16



San Diego Cal.

Oct. 1935

Red indicates NE to E winds

Numbers indicate thickness of layer in decameters

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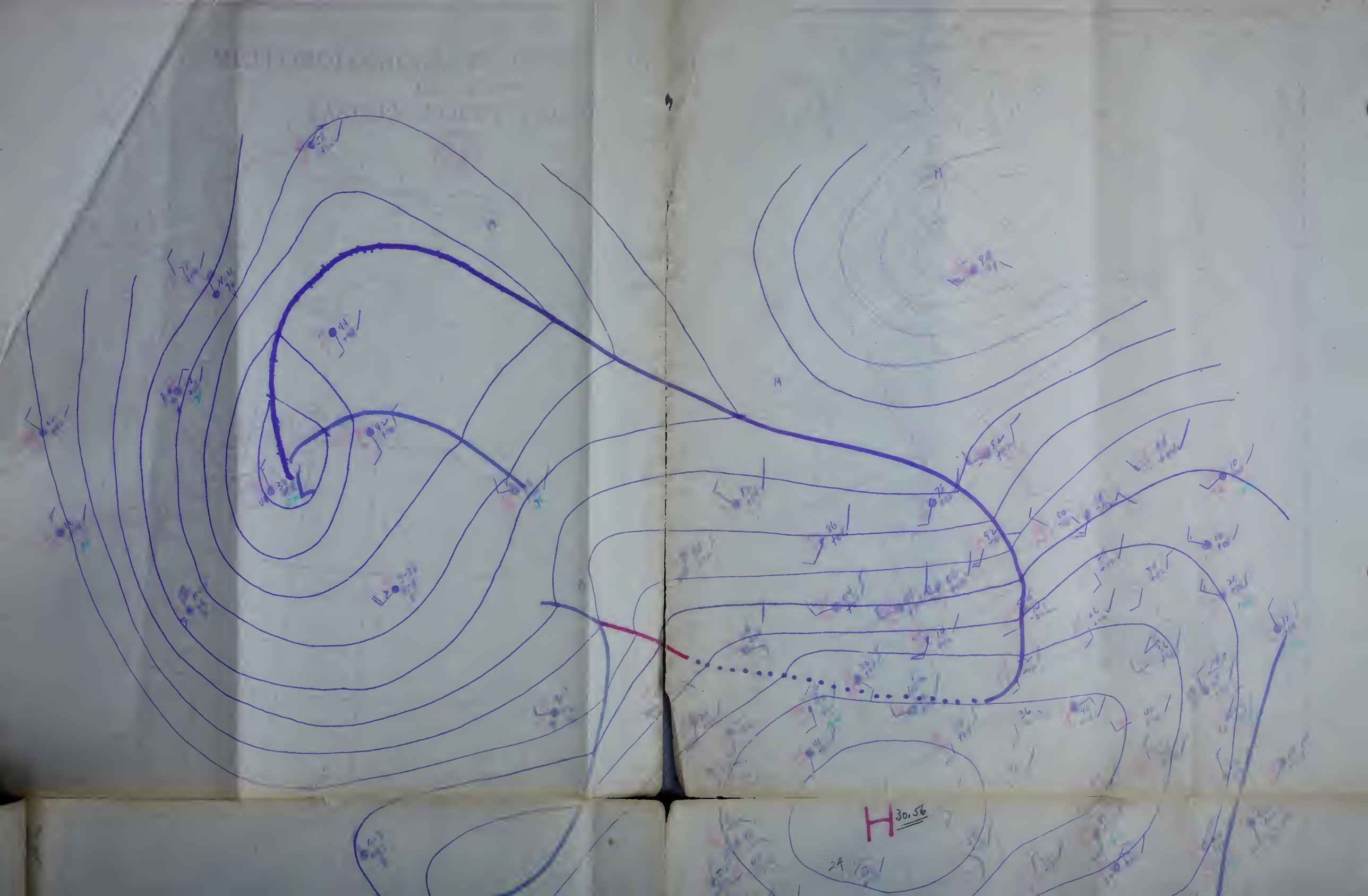
Ordinates represent potential temperatures of the dry air. Absoissae represent constant equivalent potential temperatures computed on the basis of pseudo-adiabatic convection neglecting heat of fusion. Sloping lines represent the water vapor content expressed in grams per kilogram of dry air. Dotted lines are isobars for the condensation level referred to the partial pressure of dry air.

fig. 18


H
30.56

H

H 30.56

24 hr

0500 17 Oct. 1935

Δp = .4"
24+27 = 51° F
24 temp 64° F
ΔT = 13° F

Δp = .4"

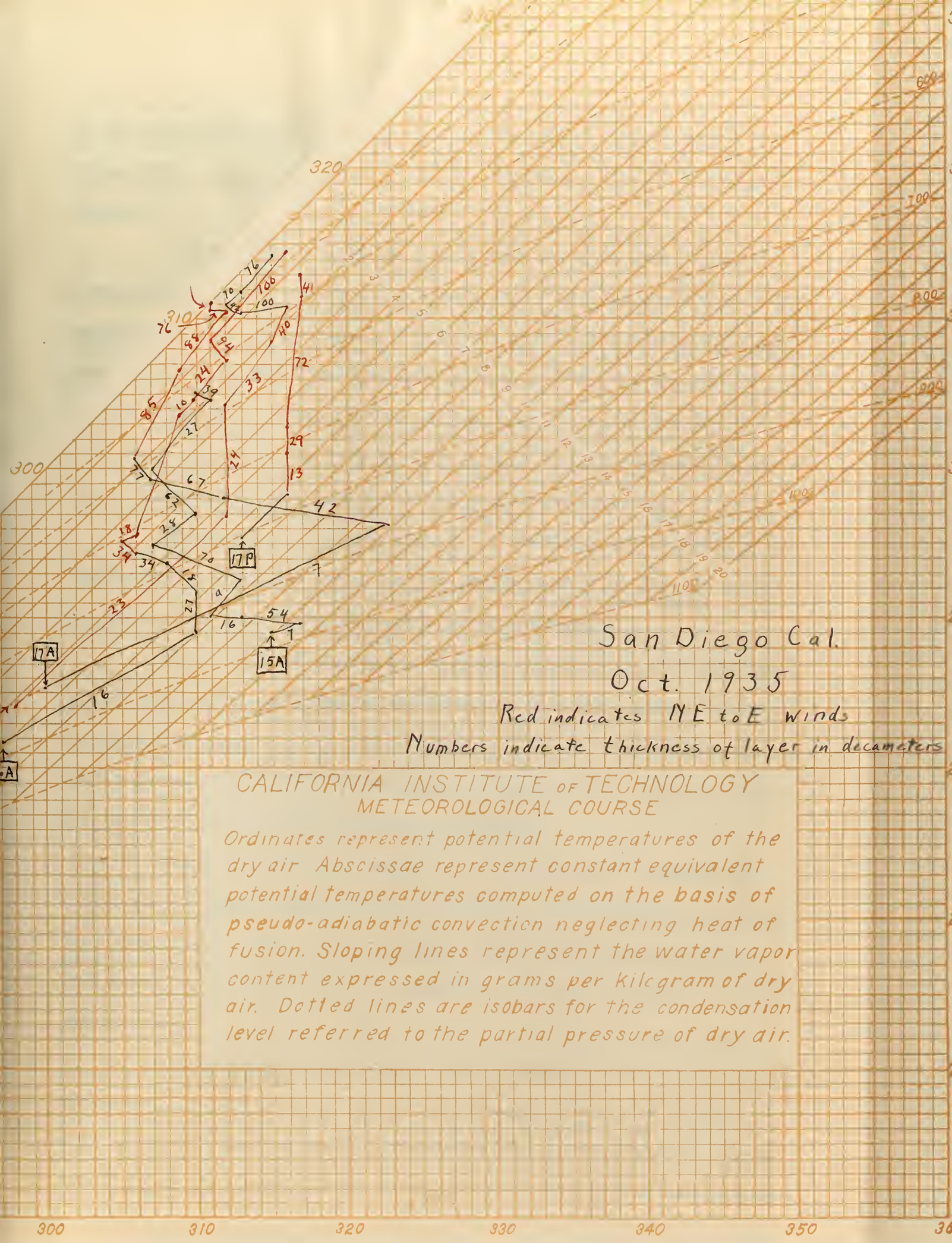

330
320
310
300
290
280
270
260
250
300
310
320
330
340
350
360
17P
15A
17A
San Diego Cal.
Oct. 1935
Red indicates NE to E winds
Numbers indicate thickness of layer in decameters
CALIFORNIA INSTITUTE OF TECHNOLOGY
METEOROLOGICAL COURSE
Ordinates represent potential temperatures of the dry air Abscissae represent constant equivalent potential temperatures computed on the basis of pseudo-adiabatic convection neglecting heat of fusion. Sloping lines represent the water vapor content expressed in grams per kilogram of dry air. Dotted lines are isobars for the condensation level referred to the partial pressure of dry air.

fig. 19

to the pseudo-adiabatic. On a Rossby diagram (Figs. 17-19) the air below 2000 m. appeared well mixed as the significant points were close together.

The San Diego ascent at 1432 October 23, 1935 showed a considerable warming of the air and a steepening of the lapse rate up to 1050 meters, then a sharp inversion. During the day the temperature increased at Mt. Wilson from 59° F at 0600 to a maximum of 70° F sometime during the day. At San Pedro the maximum temperature during the day was 59° F. This shows that the lapse rate picture changed entirely during this day from a convectively unstable one to a considerable inversion.

The Rossby diagram for the air at San Diego at 1432 October 23, 1935, shows that the air has a low θ_w similar to that in the A.M. ascent, but is now even more thoroughly mixed up to 1700 meters.

It is realized that these diagrams only show what has happened, they do not in themselves offer any means for forecasting prior to the occurrence of the Santa Ana. The condition of the air before being brought into this area cannot be shown directly as no ascents in this air during its travel through the Great Basin are available.

Santa Ana winds are described as hot, dry, dust laden, gusty winds, and the interpretation of the diagrams agrees in certain respects. The winds are very dry, having a specific humidity, w, at the surface over water, of only 2.9 grams per kilogram, where w is normally 9.1 grams per kilogram.

The hottness of the winds is not shown and during the full force of a Santa Ana with winds of 64 knots, the temperature is no higher at 0900 October 23 than it was at 0900 October 19 and 20 and only 2° warmer than October 21. In mild Santa Ana conditions with light or even westerly

winds temperatures do become very warm for the season, but in the direct Santa Ana current with strong winds, the air is not warmer than seasonal temperatures.

θ, for the lower 1800 meters on October 23, averaged almost 10° A less than the usual θ, as did θE.

With these factors in mind, it is thought that the question which arises of how a hot mass of air displaces a cold one, can be answered satisfactorily.

The air in this case is a fresher type of Polar Pacific air than that which was present in the vicinity of Los Angeles, and even though it is warmed by subsidence, it still has a lower temperature, θ and θE than the air which it displaced.

There was a sounding available for Spokane, Washington, elevation 610 meters, in the northern part of the Great Basin on October 21, 1935. This gave

	θE	w
surface	290	4.2
990 m.	297	4.4
2030 m.	298	3.6
2280 m.	296	2.7

and a θE at about 5000 meters of 296, w .3.

The air which appeared at San Diego and San Pedro had θE up to 1900 m. of 300 to 301. This is not far different from that at Spokane two days before (See Fig. 14).

In the December 19, 1935 case, no such clear cut discontinuity in θE appears in the ascents at San Diego (see Fig. 15). The air which was over Spokane on the 13th, 14th and 15th of December appears rather warm, and this Santa Ana failed to develop until it was aided by a LOW to the south of California.

With the formation of a LOW to the south of the Santa Ana area,

it would not be necessary for the air from the Great Basin to displace or force air out of the Los Angeles area; it would merely have to follow around behind the air which moves around the [illegible].

In both the December and October 1935 cases, the gradients rose to .46 in hg. with the first influx of Pp air into the Great Basin, then the gradient became less. In the October 23, 1935 case a new Pp mass colder than the first then entered and build up strong gradients and some of the air emerged at the Southern California coast. In the December case no fresh cold Pp air was supplied to the Great Basin [illegible] but the low circulation induced a flow which produced Santa Ana winds.

Complete continuous records of aerograph soundings are not available for many cases of Santa Anas, but those included in this paper and other fragmentary records promise interesting results.

More complete records from Mt. Wilson supplemented by records from such places as Mt. Echo and Mt. Palomar would prove very valuable in any study of upper air conditions. Aerograph records from the Great Basin would be of inestimable value.

If aerograph ascents from the Great Basin were available, the question of the importance of stability of the air could be definitely solved. Another and nearly certain method of forecasting whether the Santa Ana would reach the surface, or not, would also be available. If the temperature of the air in the Great Basin were known from aerograph ascents, it could be found whether the air is cold enough to undergo the adiabatic heating of the descent to San Pedro Harbor and still be able to displace the air there.

One device which might prove of some advantage is to use the temperature of the air at Pontona, add nine degrees F. to that, which

would be the adiabatic heating for a descent of 1700 feet, and see if the resulting temperature were low enough for the air to reach the Harbor.

This device might prove valuable but at this time no attempt has been made to prove whether or not it will invariably work. Lt. D. H. Collins, U.S.N. has stated that this method proved valuable during 1935 and 1936.

Isobars

The drawing of isobars on a weather map is of great importance in forecasting weather, and in forecasting Santa Ana winds offers significant problems.

Many additional difficulties are involved in map analysis over the United States from the Rocky Mountains West, because of the scattered network of Weather Bureau stations, and because of the high elevation of these stations, some of which are over 7000 ft. above sea-level and many over 4000 ft. Pressures for all of these stations are reduced to sea-level, by means of a formula containing empirical values; hence sea-level isobars are not truly representative of pressure distribution.

The airways stations help make a closer network of stations and offer considerable aid in analysis. It is true that these pressure reports are more erratic than the Weather Bureau stations but with steep pressure gradients the drawing of isobars is much simplified with the help of such stations.

Maps for October 17 and 22, 1935, analyzed by Dr. Sverre Petterssen, show a distinct frontless trough along the coastal ranges of California. Maps seen by the writer which were drawn using only the principal Weather Bureau stations do not show the trough.

This trough appears when a [illegible] builds in over the Great Basin, and is undoubtedly an effect caused by the high mountain ranges along the coast. It is conceivable how these mountains might act as a wall changing the normal circulation of a [illegible] considerably. (This is the Barrier Circulation explained in Physikalische Hydrodynamik, paragraph 174).

From the isobars on the accompanying maps October 13 to 04, 1935, it appears that one [illegible] is located in the Pacific off the California coast with a circulation which might give an onshore component at San Pedro. The other [illegible] having isobars which is continued with direction unchanged across the mountains would give NE or offshore winds at San Pedro. (With a well developed [illegible] remaining in the Pacific, having a separate center, only high Santa Anas have occurred in cases studied).

Easterly to North Easterly winds actually do appear at varying levels from [illegible] 3.0 m/s at 718 m. at 0700 on October 15, 1935, [illegible] 3.8 m/s at 901 m. at 1300 on the 16th., [illegible] 4.8 m/s at 414 m. at 0710 on the 17th, [illegible] 5.0 m/s at 1118 m. on the 17th, with W to N winds below these levels. On these dates it is probably the proper interpretation that there is a circulation in the Pacific, off Southern California, at lower levels, which has sufficient onshore component and is sufficiently cold to force the air from the interior, which was coming out Cajon Pass, aloft. During the latter part of the day the sea breeze effect aided in this.

In cases where the development of a [illegible] over the Great Basin may cause a Santa Ana, the isobars to the coastal trough are oriented NE to [illegible] from this trough inland.

When a LOW develops to the south or southeast of the Los Angeles area and the pressure is high in the Great Basin, the trough is wiped out and the isobars run from NNE to SSW from the Los Angeles area.

When more complete and accurate observations of pressure wind direction and sounding balloons are available from the Pacific Ocean the true character and synoptic importance of this trough can be evaluated. Stations such as San Nicholas Island, Mt. Wilson and Mt. Palomar could be of great value for such investigations.

Conclusions

1. Santa Ana winds at San Pedro are caused by two different types of flow:

   A. Cold Pp air forced out of the Great Basin by large pressure gradients, through the Coastal Range Passes and over the Coastal Range.

   B. Pp air induced to flow out of the mountain passes by a LOW forming to the South or Southeast of San Diego.

   (A third type probably occurs which is caused by pressure gradient accompanied by the passage of an active cold front which lies NE and SW and moves down more or less perpendicular to the Coastal Range)

2. Santa Ana winds occur at the surface only during colder months of the year.

3. Santa Ana winds can begin at any time, day or night, but occur more often during the night.

4. When pressure is high in the Great Basin and a LOW develops South or Southeast of San Diego, Santa Ana winds as high as 30 knots can occur with a gradient of .40 in.hg. from Winnemucca to Los Angeles. With a gradient of .62 in.hg. velocities as high as 50 knots can occur.

5. When high pressure occurs in the Great Basin, gradients as high as .52 in.hg. from Winnemucca to Los Angeles may occur without causing Santa Ana winds at San Pedro.

6. When a Santa Ana occurs there is a relation between the gradient from Winnemucca and the average hourly velocity which results at San Pedro Harbor (Fig. 10).

7. Northeasterly to Easterly isobars extend from the Eastern side of the Coastal Ranges inland during a Santa Ana caused by high pressure in the Great Basin.

8. East North East to East South Easterly isobars extend from the Los Angeles area inland during Santa Anas caused by the formation of a LOW, South of South East of San Diego.

9. A thorough analysis of weather maps is necessary to forecast Santa Ana winds successfully. This analysis is aided by use of Airways Stations as well as Weather Bureau Stations.

9a. It is necessary to know the structure of the Great Basin air which may cause a Santa Ana as the relative stability and temperature of this air is an important factor in deciding whether the air will reach the surface at San Pedro or pass out aloft. At present only indirect methods and the irregular aerograph ascents from Sand Point and Spokane, Washington are available to aid in this determination.

10. With a careful map analysis, it is practicable to forecast gradients to Los Angeles 12 hours in advance of the development of Santa Ana winds.

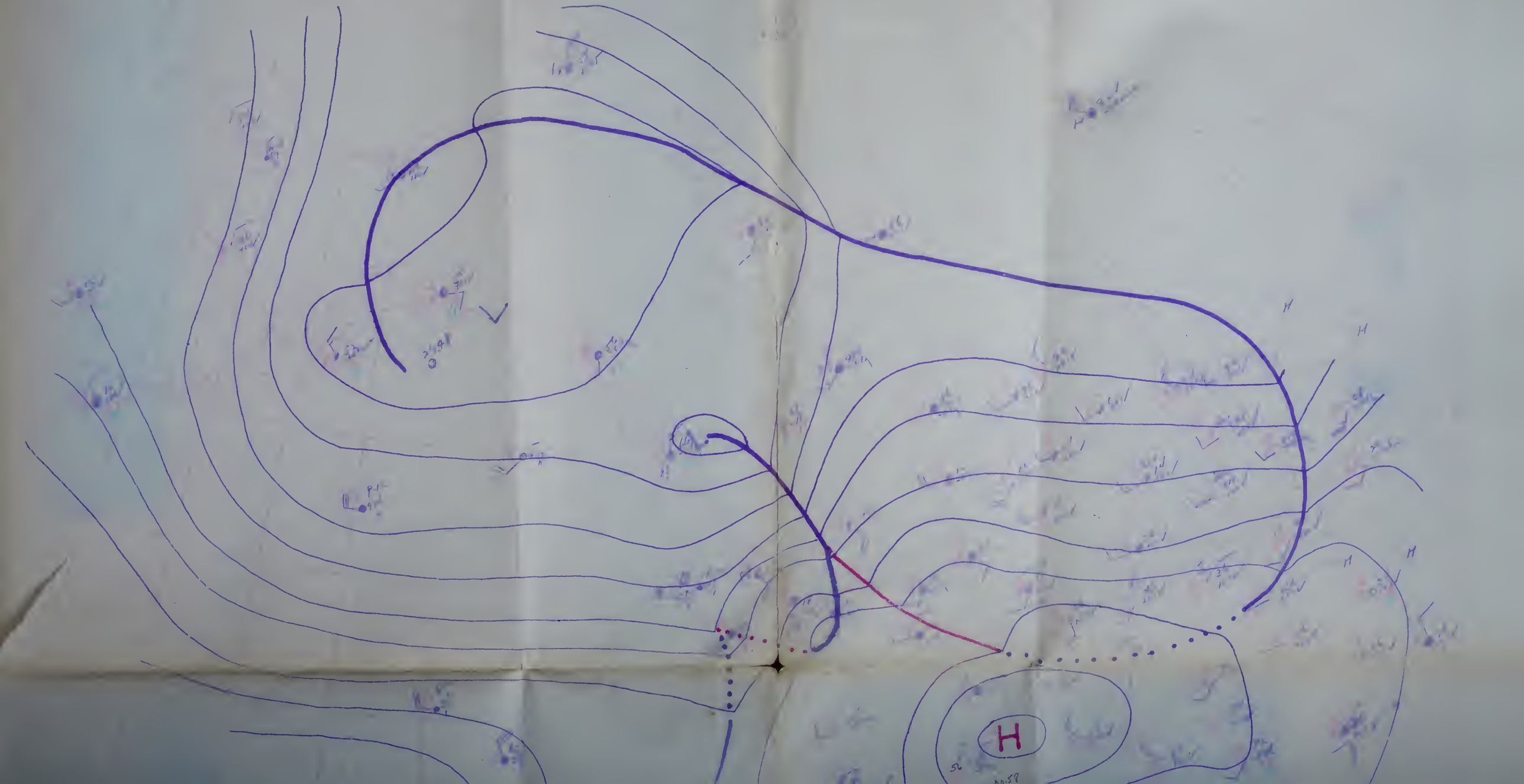
11. It is necessary to estimate the development of the Pacific HIGH, as if it retains a separate center off the coast it is probable that only a HIGH Santa Ana will result.

12. Polar Pacific Air with a relatively long trajectory over the Pacific or Returning Polar Pacific air, will be less likely to produce Santa Ana winds than fresh Polar Pacific air which has a short trajectory.

13. No cases of Santa Anas caused by Pc air have been found in this study, but Pc due to its low temperature might cause a Santa Ana.

14. No key stations or any one synoptic factor has been found which will enable forecasting whether a Santa Ana will be high or will reach the surface.

15. Air flowing out of San Gorgonio Pass probably is a major influence in directing the flow of air from El Cajon Pass to Santa Ana Canyon.


H
H
H
H
H

H

H

56

30.58

30.06

1700 Oct. 17 1935

Δp=.52

56+27 = 83°F

WI

L

H

H

H

H

30.54

86

L

30.00

18 Oct 1935 0500 PS

Δp = .54

38 = 27 = 63° F

1 = temp 65° F

H

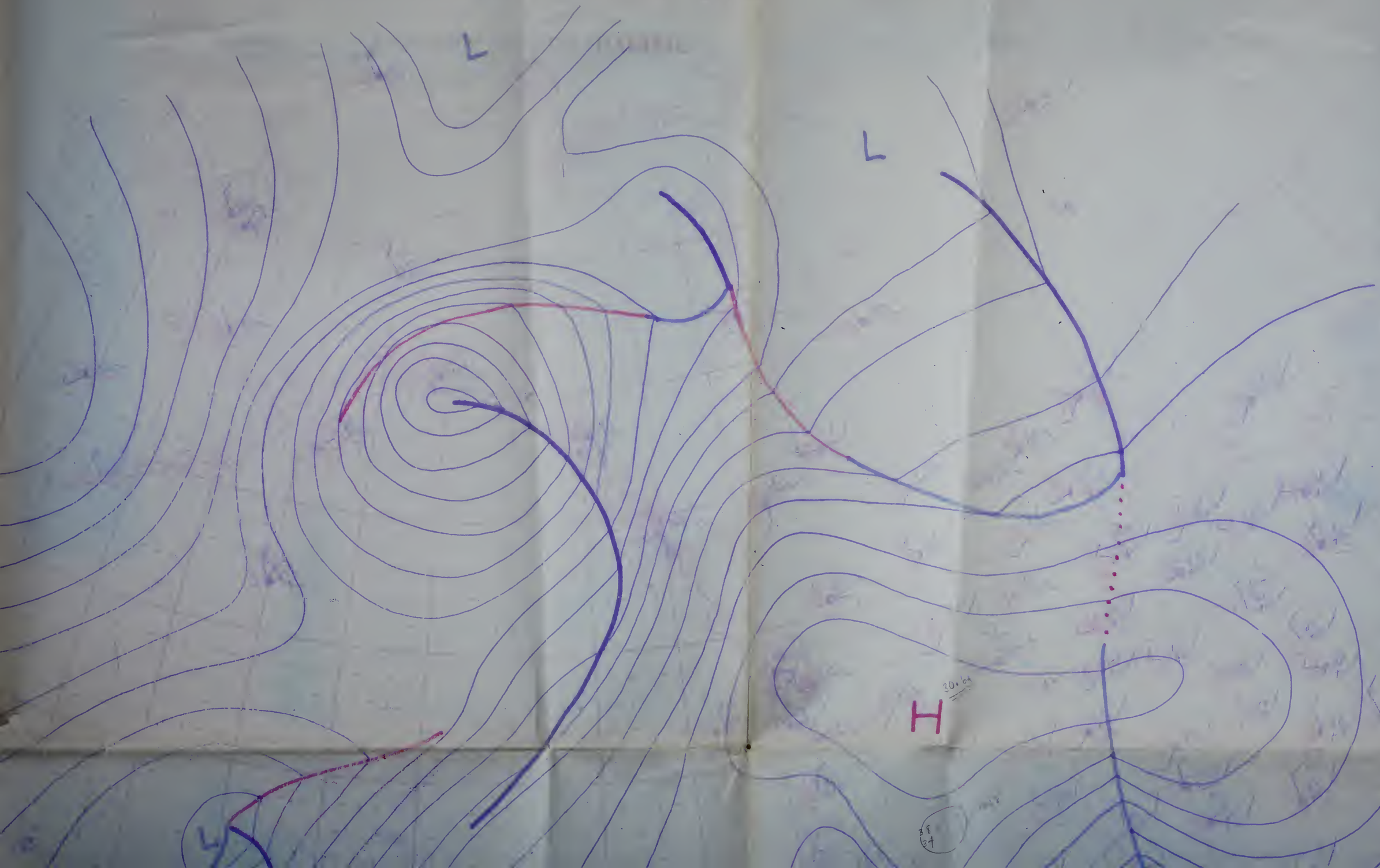
H

H

H

H

18 Oct 1935 1700 PS


L
L
H
1020 hPa

H

30.64

30.58

L

L

$\Delta p = .66$

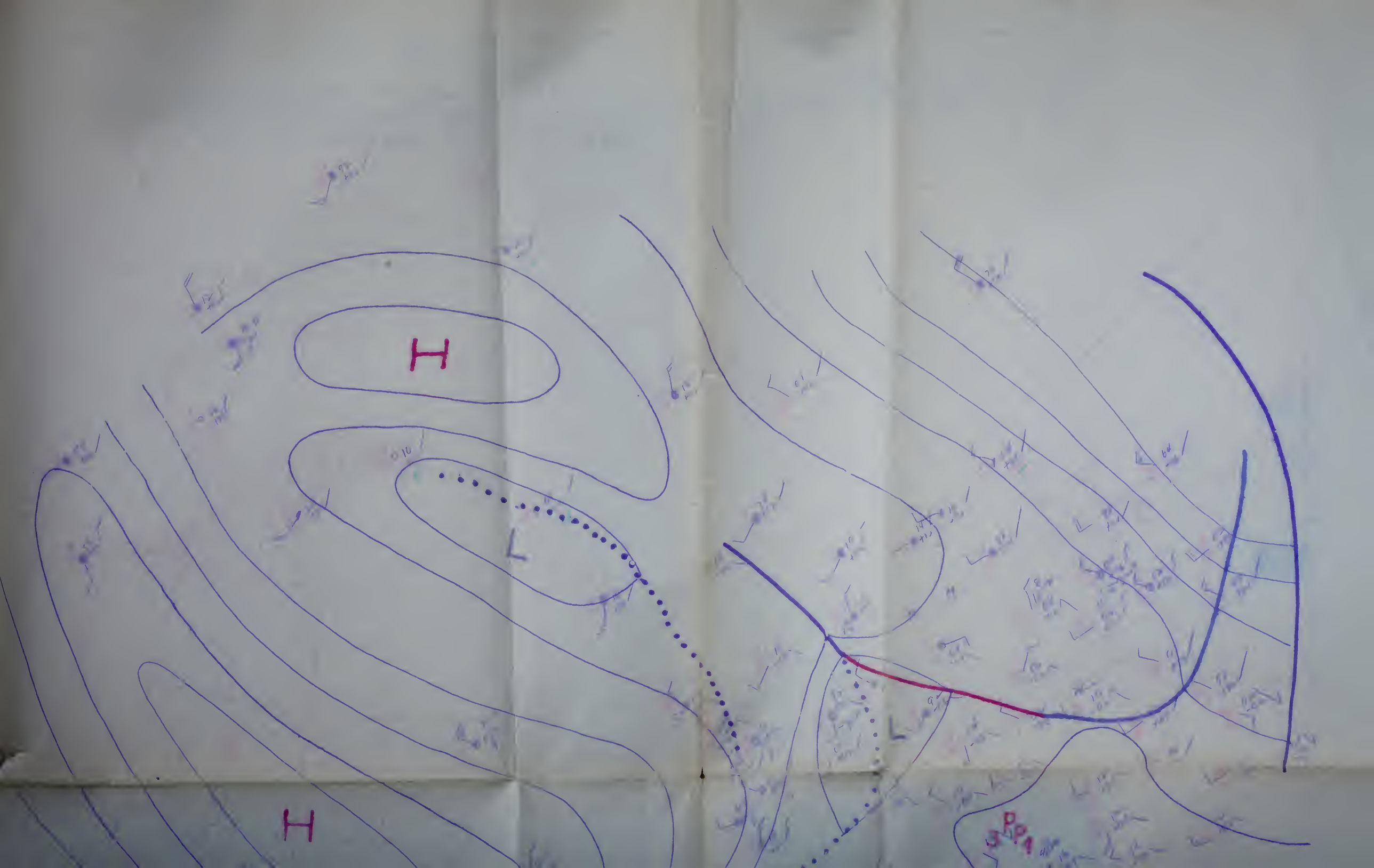
$3\varepsilon + 7 = 65°F$

L.A temp = 70°F

ΔT 5°F

WI + M

Sandy Hook pressure at high tide


H
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L
PP

H

L

$3^{P}P_4$

H

$3^{P}P_3$

19 Oct 1935 0500 PS

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H

L

19 Oct. 35 1700 PS

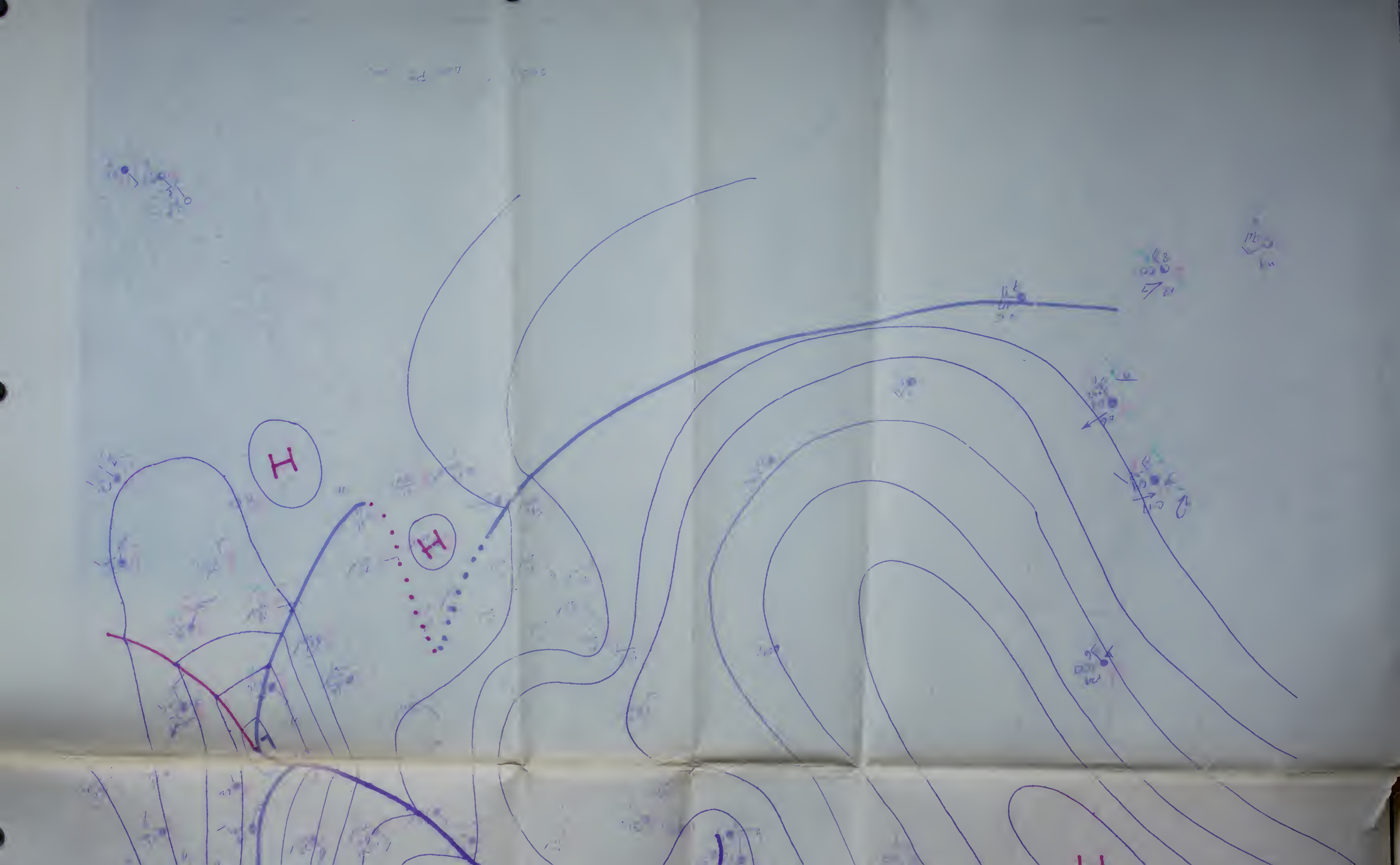
L

H

H

H

P10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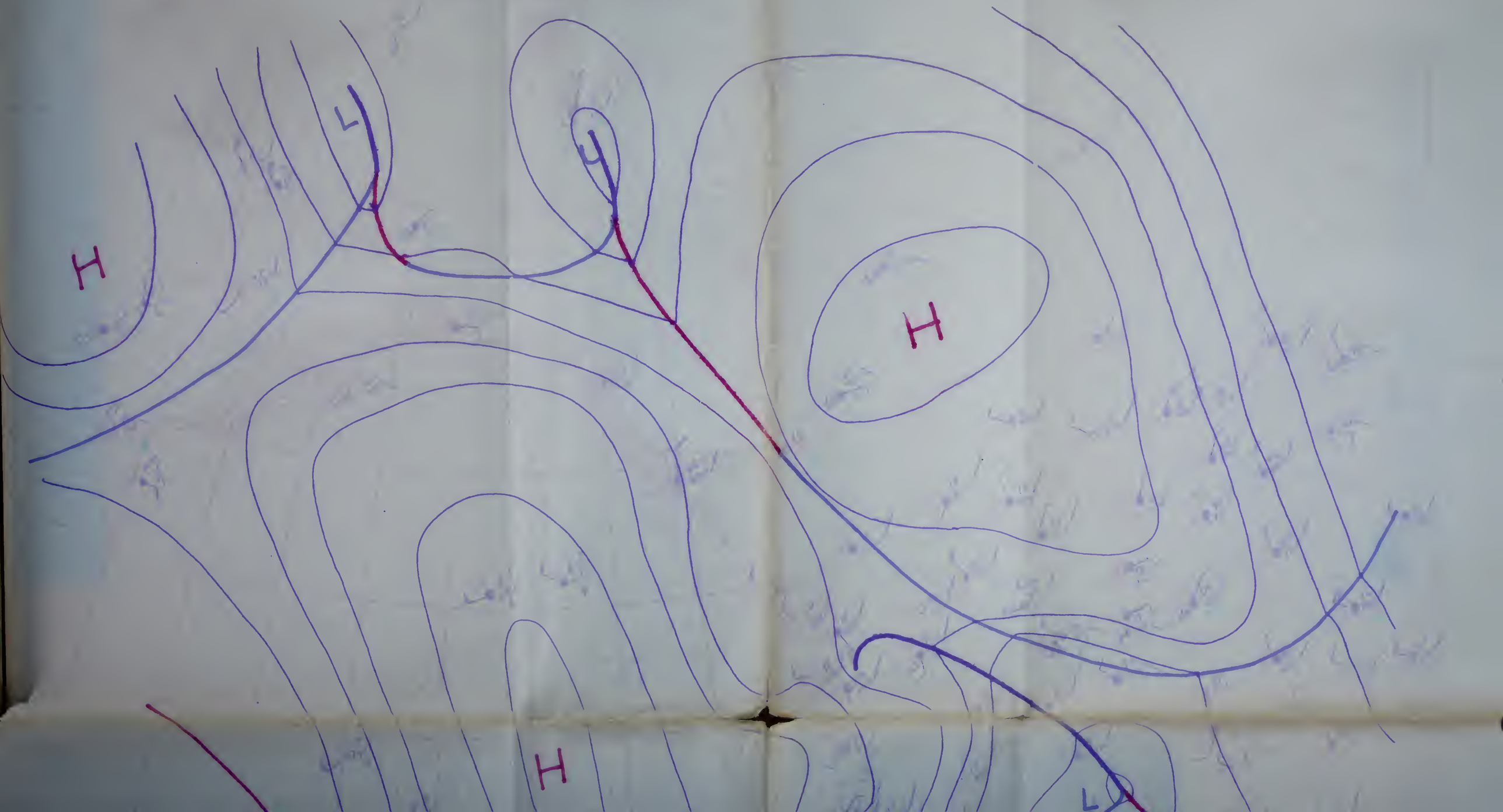
H
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METEOROLOGICAL [illegible] CHART

OF

EASTERN NORTH PACIFIC

L

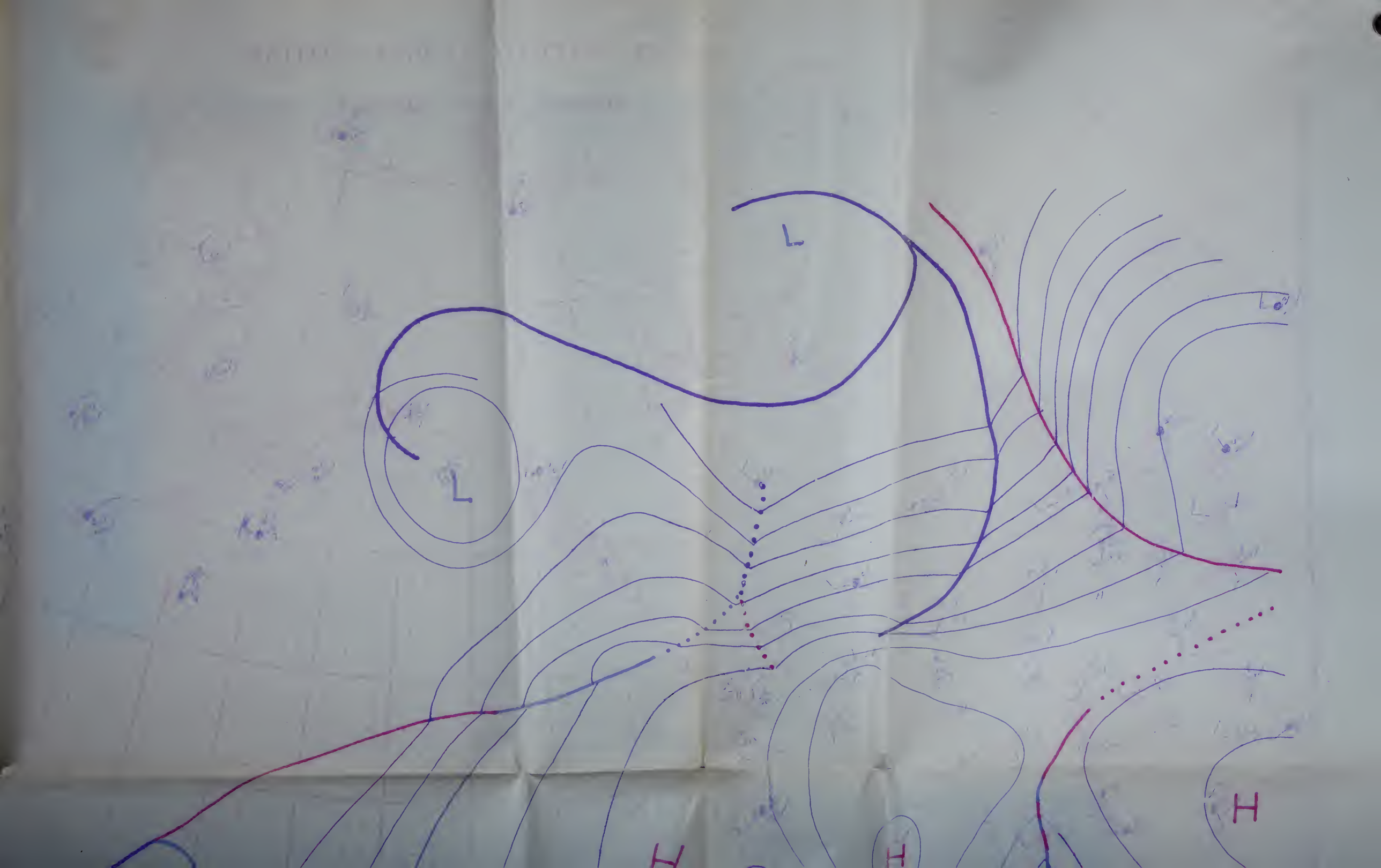
L

H

H

H

L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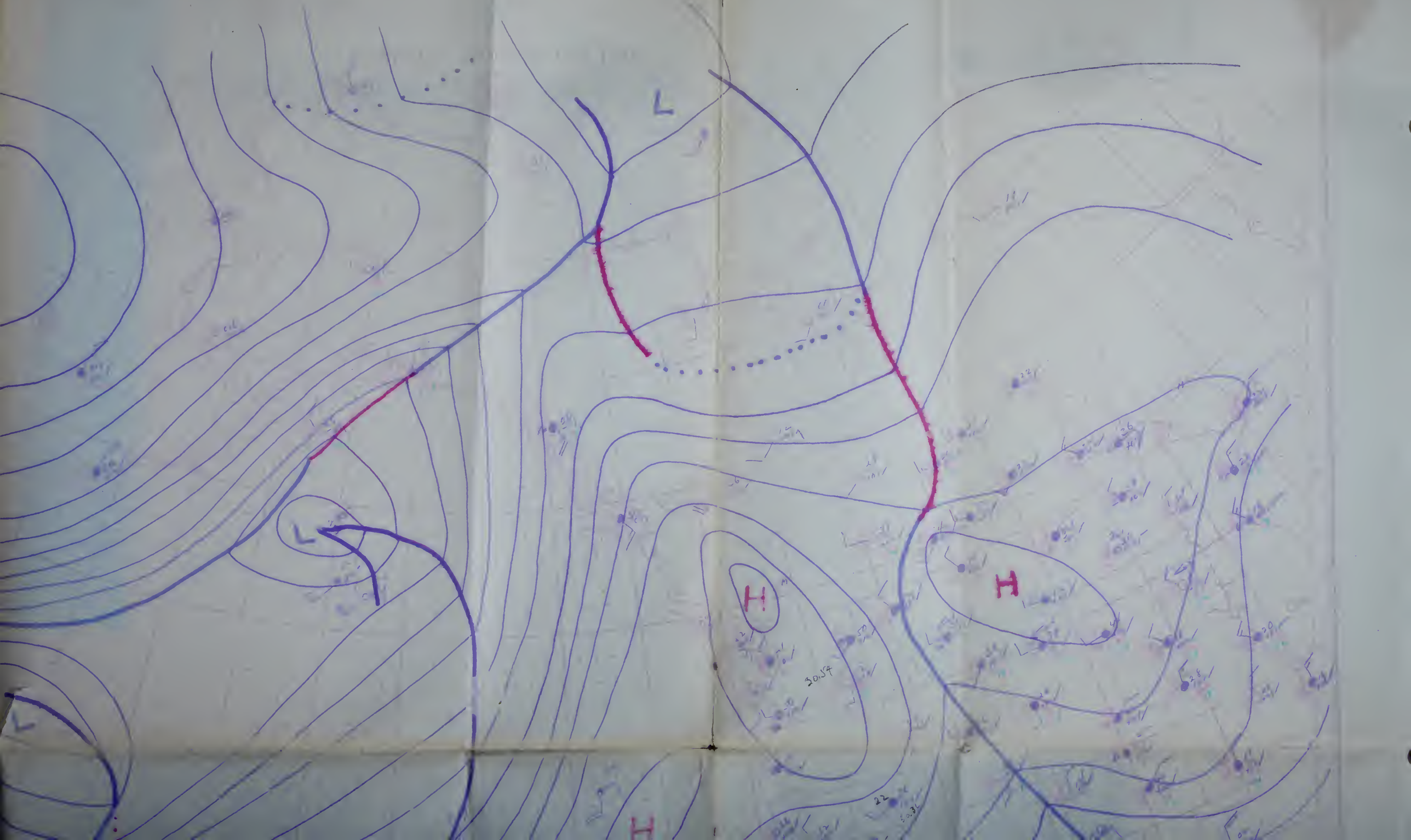
21 Oct. 193(
0500 PS


L
L
L
H
H
H

H

30.54

22

30.32

H

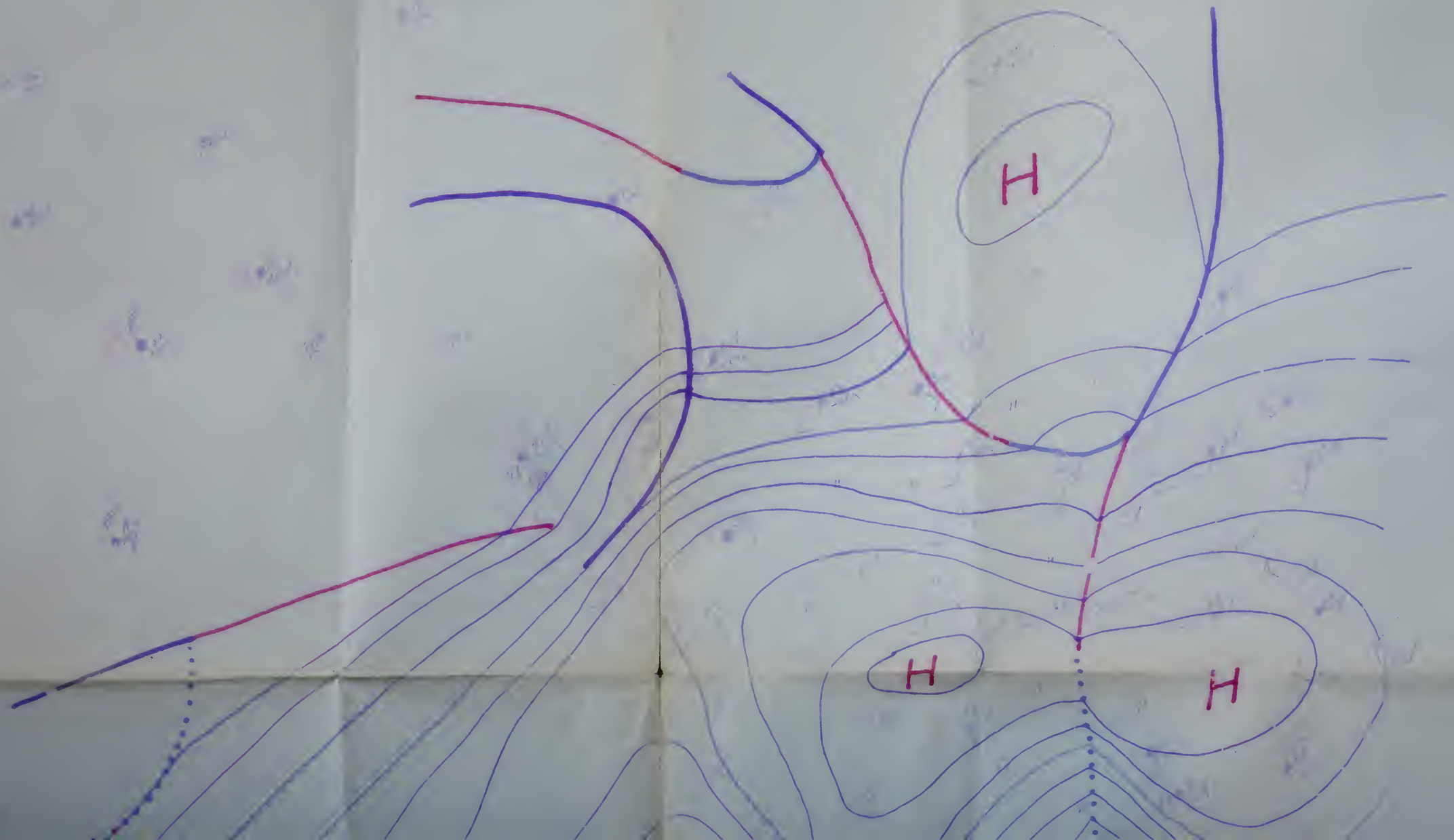
L

Δp = .38

22+27 = 49° F

98 F

49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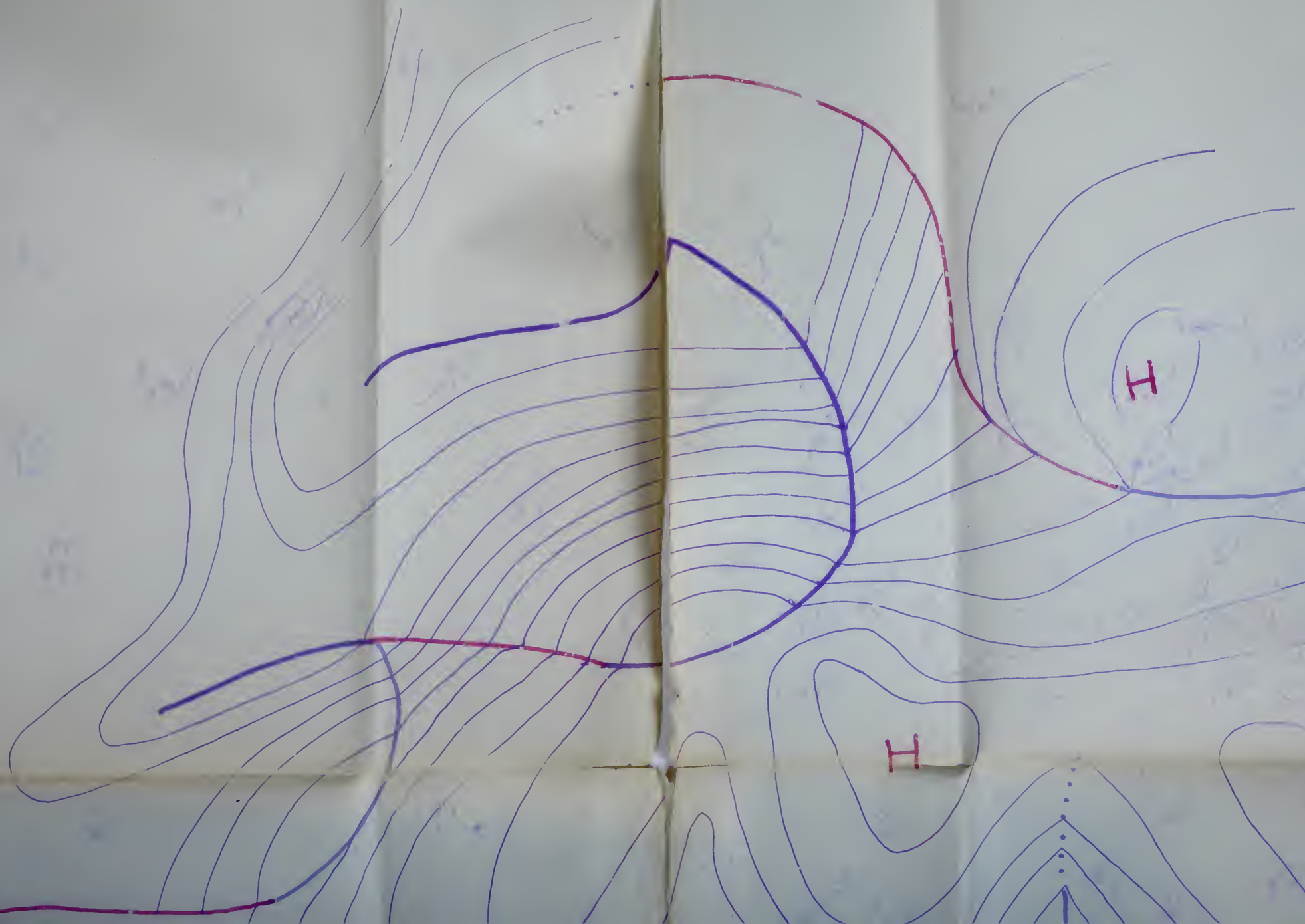
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24 Oct 1935
1760 PS

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Thesis
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